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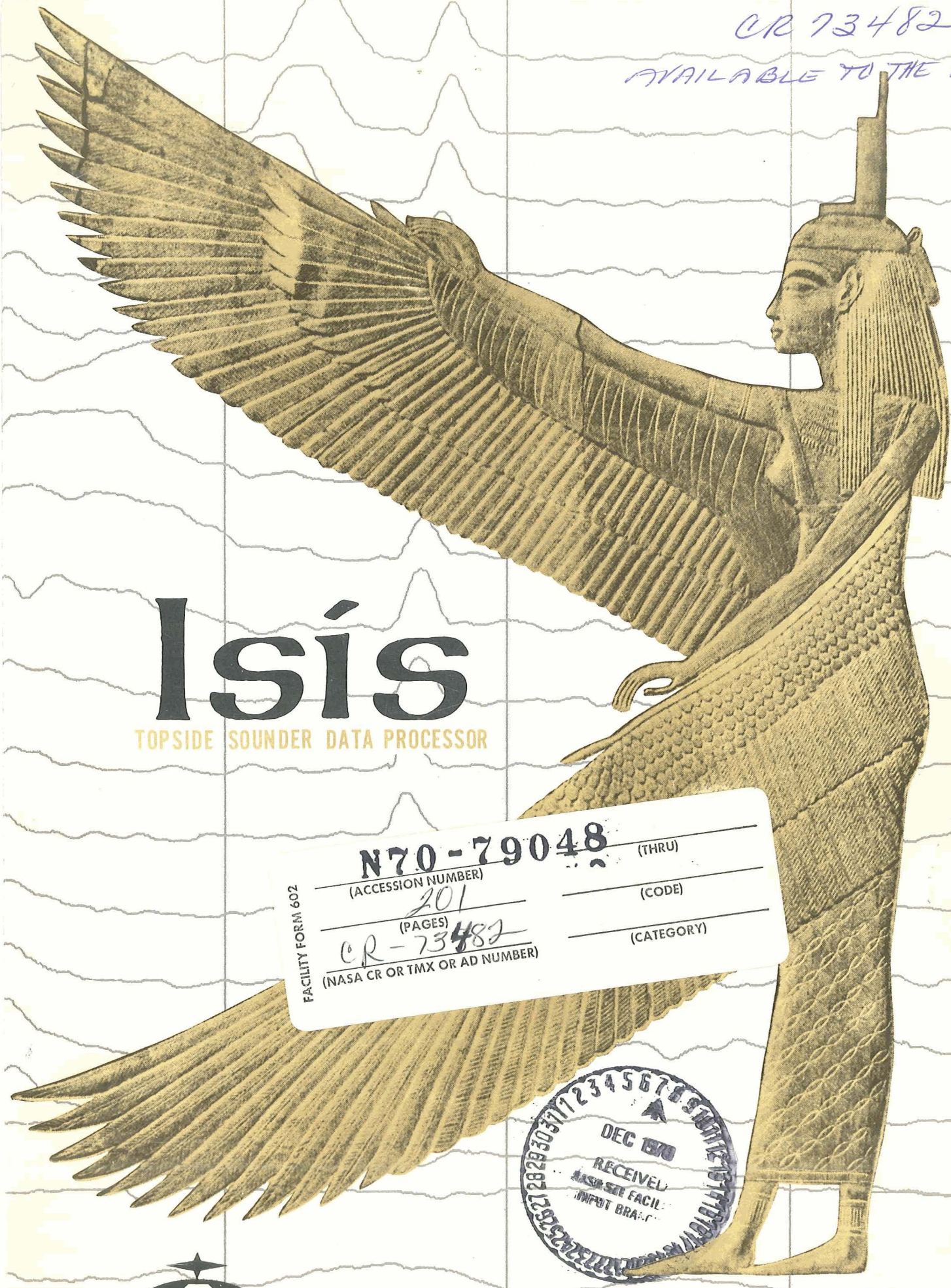

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TOPSIDE SOUNDER DATA PROCESSOR

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STUDY REPORT, PART I

ENGINEERING STUDY AND PRELIMINARY DESIGN OF INSTRUMENTATION FOR THE SCALING AND EDITING OF IONOGRAPH DATA

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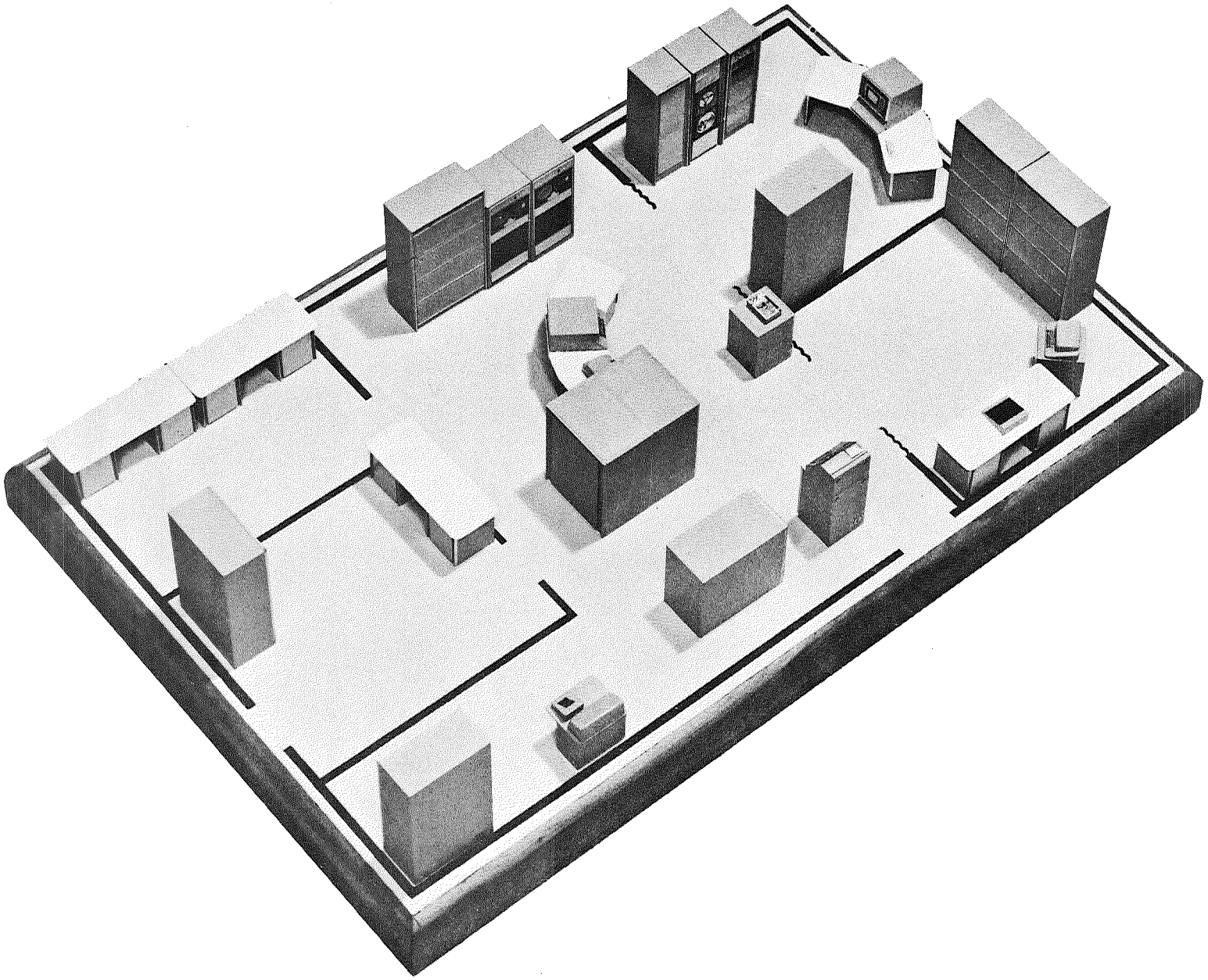

TOPSIDE SOUNDER DATA PROCESSING SYSTEM

ACKNOWLEDGEMENTS

Many of the new ideas in Topside Sounder Data Processing presented in this report were an outgrowth of discussions with Dr. Lawrence Colin and Dr. K. L. Chan of NASA/Ames Research Center. The concept of closed-loop operation was outlined in private communications with Dr. G. L. Nelms of DRTE. We are also indebted to Dr. Nelms and his staff for an appreciation of the importance of a trained operator as the "man" in the man/machine communication link of a Semi-Automatic Topside Sounder Data Processor.

The simulated man/machine communication link, including the CRT display interface hardware, was designed by Robert Logan. The X-Y plotter mechanism for cursor spot control was implemented by James Bybee. Simulation software was written by Nathan Epstein.

ABSTRACT

A study of the problems of processing telemetry data from satellite-borne topside ionospheric sounders shows conclusively that new data processing methods and equipment are required that will provide the capability needed for processing complex, high-altitude ionograms, and that can keep pace with present and future Topside Sounder data processing workloads.

High-altitude Topside Sounder data being received from the Alouette II Satellite is of crucial importance in ionospheric investigations. Frequently, however, ionograms derived from high-altitude data are so complex that they do not provide sufficient information for unambiguous scaling. The difficulties that are now being encountered in interpretation and scaling of Alouette II high-altitude records are indicative of the more complex problems that may be expected in the data received from the ISIS series satellites that will operate at high altitudes and during high sun spot numbers.

From a practical standpoint, these complex, high-altitude ionograms cannot be processed by present open-ended processing procedures. It is necessary that a closed-loop type processing procedure be implemented that will allow the operator to revise her trace interpretation after seeing the results of calculations based on her first interpretation. This type of closed-loop operation requires data processing equipment having

a conversational mode man/machine communication link that will enable the operator to hold a meaningful conversation with a computer in real-time.

In closed-loop processing of a complex-type ionogram, an acceptable final N(h) profile is computed from a set of $h_x'(f)$ data points that are selected by a process of successive approximation. Scaled and computed data points are compared with the ionogram on a computer-controlled cathode ray tube (CRT) display. If the comparison is unsatisfactory, scaled data points from a modified interpretation of the trace are then compared with data points recomputed from the resulting N(h) profile, and the cycle repeated until the data point comparison is acceptable to the operator.

The critical elements of a man/machine communications link were simulated in enough detail to demonstrate the feasibility of the basic concepts involved, and to experiment with some of the psychological factors involved in a man/machine feedback loop. The design specification of a Semi-Automatic Topside Sounder Data Processing System is contained in Part II of this report. The proposed system combines the unique pattern recognition capabilities of a human being with the power of an on-line digital computer operating in real-time in something of an optimized way. In this system data is processed directly from the analog magnetic tape; the usual step of converting from analog magnetic tape to filmed ionograms is not required.

Radar echo pulse amplitude information that is substantially obscured in the film ionogram process is preserved in the proposed system and is made available to the operator in the form of an augmented A-scan display to the right of the electronic ionogram picture on the CRT display.

Mixed-mode processing is a special form of closed-loop operation that can be implemented with the proposed processor. This mode uses a composite method of processing appropriately selected data points from both the X-wave and O-wave traces for use in computation of the N(h) profile. The electron density computed from an initial few $h_x'(f)$ data points gives corresponding laminations in the N(h) profile that are used to compute $\overline{h_o'(f)}$ data points for display on the CRT. These data points become the reference for scaling $h_o'(f)$ data points in order to compute additional laminations in N(h). In effect, mixed-mode processing provides a method for piecewise computation of laminations in the N(h) profile that will assist in defining the complete $h_x'(f)$ set of data points that are then used for the final N(h) profile computation.

Ionogram data extrapolation is another method of processing that can be implemented with the proposed processor. In this method, the location of the X-trace on the next ionogram is predicted by extrapolating the N(h) profile from the N(h) profiles of previously processed ionograms in the same pass of the satellite,

and computing $\overline{h_x'(f)}$ data points using the inverse program. The method is based on extrapolating data at equally spaced increments of true height which results in an almost ideal distribution of laminations in the resulting N(h) profile.

With a computer-controlled semi-automatic data processing system, closed-loop processing of filmed ionograms can be implemented at a modest additional cost. In this method, a computer-controlled CRT display is conveniently located adjacent to the optical data reader. Digital data from the reader is input directly to the computer and displayed on the CRT. A movable cursor spot on the CRT continuously follows the regular cursor position of the data reader, allowing the operator to relate information on the CRT with the projected film ionogram on the data reader. With this modest addition, it is possible to utilize closed-loop, mixed-mode, and ionogram data extrapolation techniques for processing conventional filmed ionograms.

The capacity of the recommended system to process ionograms directly from analog magnetic tape is more than 60 low-altitude ionograms per hour, or at least 45 high-altitude ionograms per hour. This estimated capacity represents an average figure where maximum rates with favorable conditions exceeds 200 ionograms per hour. There is sufficient surplus machine time to concurrently process filmed ionograms via a peripheral film digitizing console with CRT display, that time-shares the system central processor.

The design of the proposed system is planned for future expansion capability to handle an increasing workload, meet the additional requirements of future satellites, and be able to accommodate to changing needs as new ideas, techniques and procedures are developed.

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SECTION I

INTRODUCTION

1.0 GENERAL

For many years a number of international scientific groups have been investigating and studying the characteristics of the ionosphere, an ionized region in the upper atmosphere. The principal instrument employed for these studies has been the ionospheric sounder (ionosonde), which is a swept low-frequency radar which provides a means of probing the ionosphere. Earth-based ionosondes have probed the ionosphere from the bottom side for many years, and since 1962, satellite-borne ionosondes have been probing the ionosphere from the top side.

To date, three satellites have been inserted into earth orbits with various on-board experiments related to studies of the earth's ionosphere. The Explorer XX satellite (ESSA) contained multiple fixed-frequency sounding experiments. Alouette I, launched September 29, 1962, in a nearly perfect circular orbit, incorporated a swept-frequency topside ionosonde. Alouette II, launched on November 29, 1965, in a somewhat eliptical orbit, is a modified Alouette I. A third satellite, ISIS-A, is scheduled for launching in 1968, and is planned for an eliptical orbit similar to that of Alouette II.

1.1 BASIC RELATIONSHIPS

The apparent range, h', of an echo pulse from the satellite-borne ionosonde is one-half the measured round-trip time multiplied by the free space velocity

of light. This information can then be used to determine the electron density, N (of the ionosphere) as a function of true height, h, and the geographic location. The true depth of penetration of the ionosonde pulse is less than the apparent range because the velocity of propagation is reduced by the ionized medium through which it travels.

The relationship between true height and apparent height is given by the equation :

$$h' = \int_{h_s}^{h} \mu' dh$$

where h_s is satellite height and μ', the group refractive index, is a function of the sounder frequency, the electron density of the ionosphere, and the intensity and dip angle of the earth's magnetic field. h' is negative in a topside sounding.

The Topside Sounder video signal is telemetered from the satellite, on command, to ground stations over which it passes, and is recorded on magnetic tape, together with frequency calibration markers, a coded timing signal, and a reference frequency. Data from other satellite-borne experiments including housekeeping data, are also recorded at this same time.

This report confines itself to discussions regarding the processing of Topside Sounder data with emphasis on techniques for automatic and semi-automatic scaling, editing and computation of electron density profiles from magnetic tape and/or ionogram films.

1.2 CURRENT DATA PROCESSING PRACTICES

At present, the video data recorded on magnetic tape is converted to a film ionogram, as shown by the typical format, figure 1-1.

The film ionogram is made by playing back the magnetic tape, and triggering the sweep of an oscilloscope with the line sync pulses (which correspond to the radar pulse start time) and modulating the Z-axis (intensity) with the radar video signal. The oscilloscope image is photographed on 35 mm film with a slow continuous-motion camera. Range markers, frequency markers, and time annotation are added to complete the film ionogram.

The filmed ionogram is then projected onto the scaling table of an optical data reader. After range and frequency calibration, an operator digitizes an interpretation of the selected echo trace(s). The output of the data reader may be in the form of punched cards, perforated paper tape, or digital magnetic tape. These computer-compatible documents are then edited, to detect overt operator errors, and the final h'(f) data becomes the input data to a general-purpose digital computer for computation of the N(h) profile.

1.3 PROCESSING IONOGRAMS FROM HIGH-ALTITUDE DATA

The high-altitude data being received from the Alouette II satellite is of crucial importance in ionospheric investigations. However, many ionograms derived from high-altitude data are exceedingly complex, and are often very difficult for an operator to properly interpret and scale. The vertical reflection trace is frequently not discernible in these high-altitude ionograms because of the presence

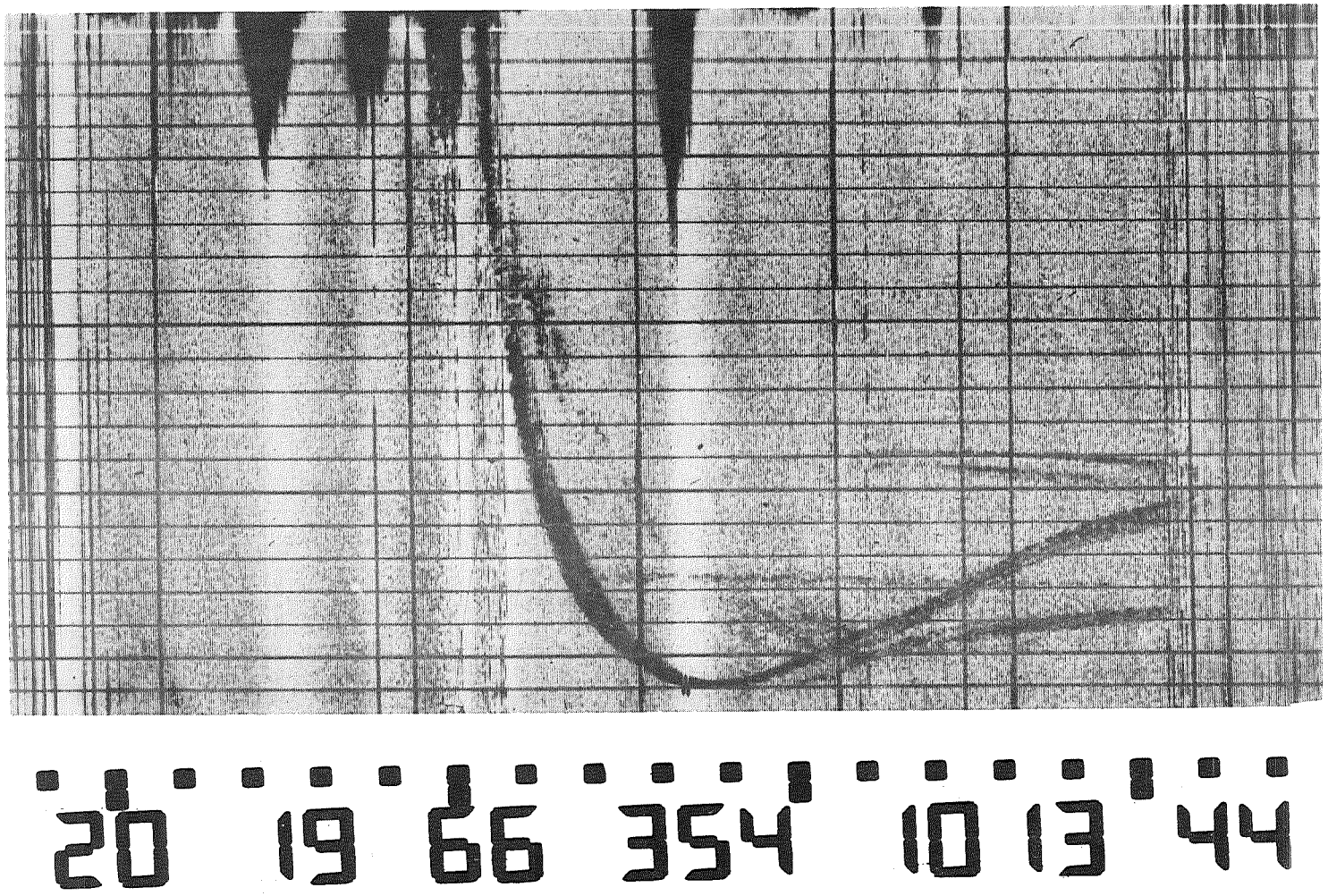

FIGURE 1-1. ALOUETTE II NEAR APOGEE TOPSIDE SOUNDER IONOGRAM

of field-aligned traces that often appear for part of the record. O-wave traces are usually present for part of the record. The O-wave traces tend to be relatively free of field-aligned echos and are assumed to result from vertical propagation. However, continuous X-wave or O-wave traces, due to vertical reflection, are very difficult to identify, with any confidence, from among the several traces or spread echos that are usually present. Thus, the ionogram by itself does not always provide sufficient information for an unambiguous scaling. The information is probably available in the data, but it cannot be obtained from the ionogram by inspection, even by an experienced research scientist.

Some future ISIS satellites are expected to operate at high altitudes and during high sun spot numbers, therefore, topside sounding records can be expected to become increasingly complex as the ionospheric research program continues. Thus, the difficulties that are now being encountered in interpretation and scaling of Alouette II high-altitude records are indicative of the more complex problems that may be expected in the data received from the ISIS series satellites.

1.4 NEW METHODS

Some suggested methods of dealing with the additional complexities encountered with Alouette II high-altitude data are as follows:

1. Make use of the information from the telemetry tapes that is eliminated or obscured when film ionograms are produced. Bypass the film ionogram step and instead process the data directly from the analog

magnetic tape using suitable computer-controlled data processing equipment.

2. Make use of data processing equipment that will allow the operator to revise her trace interpretation after seeing the result of calculations based on her first interpretation. This is a closed-loop type of operation in which the operator can hold a meaningful conversation with the computer in order to arrive at a solution by successive approximation.

3. Make use of information processed from previous ionograms in the same pass as a basis for predicting where the vertical reflection traces may be in the ionogram being processed.

The basic information available from the telemetry tapes is echo pulse time delay and amplitude, radar pulse frequency, and universal time. When the telemetry tape is converted into ionograms, much of the echo pulse amplitude information is lost, since the ionogram represents the amplitude at a particular threshold level, with only the film gray scale to provide amplitude information. Thus, the shape of the ionosonde echo pulse is largely lost in the conversion from magnetic tape to film.

1.5 FRAGMENTARY TRACES

Present procedures for most ionogram data processing specify scaling h'(f) data points from the X-trace only. The O-wave and Z-wave traces are fragmentary so that h'(f) data points from these traces cannot be used directly. However, closed-loop operation with a semi-automatic data processor having man/machine conversational mode capability affords the possibility of

utilizing the fragmentary information from the O-wave and Z-wave traces for assistance in "deciphering" the complex high-altitude ionograms.

1.6 SCOPE AND PURPOSE OF STUDY

The scope of the study encompassed the entire Topside Sounder data processing task, from magnetic tape input to final report data output. Particular attention was given to automating as much of the data processing task as possible. However, the results of the study emphasized the fact that the human operator is an indispensible part of the total data processing operation, due to the extremely complex nature of the data being processed. The human operator has a pattern recognition capability that cannot be economically approached by a machine. Consequently, in order to exploit the operator's pattern detection capabilities, a great deal of emphasis in the study was placed on the man/machine communication link.

The purpose of the study was to investigate the feasibility of automatic and semi-automatic techniques and procedures for the scaling, editing and computation of electron density profiles from ionogram films and/or magnetic tape-stored ionograms. An objective of this study was to conceptually develop more effective approaches using advanced state-of-the-art instrumentation and techniques.

The total Topside Sounder data processing task was investigated in order to prepare a preliminary design for a highly flexible and versatile Topside Sounder Data Processing System that could maintain pace with the large volume of data being recorded, and yet cope with

the complex high-altitude records that cannot be handled well by present equipment and methods.

The information compiled from the study is an adequate base from which to prepare a definitive specification for a Semi-Automatic Topside Sounder Data Processor which will meet not only the requirements that are now envisioned, but will have the growth and expansion capability to meet the additional requirements of future satellites, as well as being able to adapt to changing requirements as new ideas, techniques and procedures are developed.

It has been emphasized many times during the study that the accuracy of final data is of utmost importance, and for it to be useful, the research scientist must have confidence in its reliability and accuracy. Closed-loop processing can provide accurate data from topside soundings and inspire confidence in its validity. In closed-loop processing, an interpretation of the X-trace is scaled and the N(h) profile then computed from the resulting set of $h_x'(f)$ data points. A set of $\overline{h_o'(f)}$[1] data points are then computed from the N(h) profile and superimposed on the display CRT for comparison with the O-wave trace. If the comparison is not acceptable on the first iteration the operator can reinterpret the X-trace and repeat the cycle until the comparison is acceptable.

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[1]The $\overline{h'(f)}$ notation represents data points in the ionogram computed from the N(h) profile by the Inverse[2] program.

[2]See Note 2 page III-4

The benefits of closed-loop operation and the need for a conversational mode man/machine communications link were recognized during the earliest study phases. One important phase of the study program was to simulate portions of the man/machine communication link in order to validate proposed techniques, to gain first hand experience with the link, and to explore some of the possible tradeoffs in order to be able to better define the requirements of the final system.

1.7 TASK INVESTIGATION

The Topside Sounder data processing study was based on the following considerations:

1. All usable ionograms are to be processed. The Processor is to be designed for use in a production facility, and should be capable of retiring the current backlog of data tapes and filmed ionograms at the facility, as well as maintaining pace with the rate at which present and future topside sounding satellites are transmitting data. As a minimum performance design goal, the system should be capable of processing the bulk of the Topside Sounder data from one satellite.

2. Ionograms from high-altitude satellites are usually much more complex than the thin-line ionograms that are characteristic of low-altitude passes. Accordingly, the processor will likely require extensive assistance from a human operator when processing high-altitude recordings. As a consequence, considerable study attention has been directed to the man/machine communication link. The effectiveness of the system is critically dependent upon the

system's ability to utilize efficiently the operator's unique capacity to match patterns and tender judgment.

3. Pulse amplitude information is available on the telemetry tape, but much of this is lost when the film ionogram picture is made. It is desirable that this amplitude information be available to the operator and to the computer as an aid to trace interpretation.

4. Both the Z-wave and O-wave traces are fragmentary, but they do contain information that may be useful. Possible ways using fragmentary information in the data should be considered.

5. Present methods of scaling ionograms and computing electron density profiles consider each ionogram as an isolated problem. The scaling operator may make visual comparisons from one ionogram to the next in a given pass, but comparative information of this type is not normally available to the computer. Methods should be considered for carrying over information from one ionogram to the next. Some of the possible benefits from this technique might be to:

   a. Assist in identifying the vertical reflection trace of the X-wave where there are multiple traces.

   b. Make possible nearly full automatic processing of thin-line, non-ambiguous ionograms.

   c. Reduce processing time.

   d. Improve the level of confidence in the accuracy of output data.

6. The processor design should be planned for future expansion capability to handle an increasing workload, meet the additional requirements of future satellites, and to be able to accommodate to changing needs as new ideas, techniques and procedures are developed.

SECTION II

SIMULATION - MAN/MACHINE COMMUNICATION LINK

2.0 INTRODUCTION

One of the most important tasks in Topside Sounder data processing is that of properly scaling the X-wave and O-wave traces. This is a problem in pattern recognition that is extremely difficult for an unaided machine to accomplish, considering the almost infinite number of variations in Topside Sounder data that can occur. On the other hand, pattern recognition is a task for which a human operator is uniquely suited.

A primary objective in the design of a semi-automatic Topside Sounder Data Processor is to provide a system in which the particular capabilities of the man and machine are most efficiently utilized. Herein lies the importance of the man/machine communication link. For input to the computer, the system operator needs a program control keyboard and a display annotation system which might be a cursor spot control system, or a light pen. Information from the computer is displayed to the operator on a cathode ray tube (CRT) display, and in addition, numerical displays can be arranged near the CRT showing the frequency and range represented by the cursor spot position. Recorded time of the ionogram may also be of interest to the operator and could also be presented on a numerical display in a similar manner.

Input information from the operator should be displayed with negligible delay. This display should respond to her instructions with no perceptible delay in order not to distract her from concentrating on the pattern recognition and processing task.

The primary objectives of the simulation were:

1. Confirm that a CRT display is an adequate substitute for the normal film image, with regard to trace recognition, resolution, etc.
2. Test psychological aspects of the man-machine communication link.
3. Gain practical experience regarding minimum acceptable CRT display refresh rates.
4. Explore data compression schemes, in order to determine the required storage capacity of the refresh memory.
5. Evaluate cursor spot control characteristics.
6. Determine display CRT bandwidth requirements.
7. Determine A-Scan and CRT gray scale resolution requirements.

2.1 SIMULATION

A man/machine communication link was simulated in enough detail to check out many of the basic requirements of such a control system. A functional block diagram of the simulation system configuration is shown in figure 2-1. A photograph of the simulator, figure 2-8, is located at the end of this section. A close-up view of the large-screen CRT display oscilloscope with the cursor

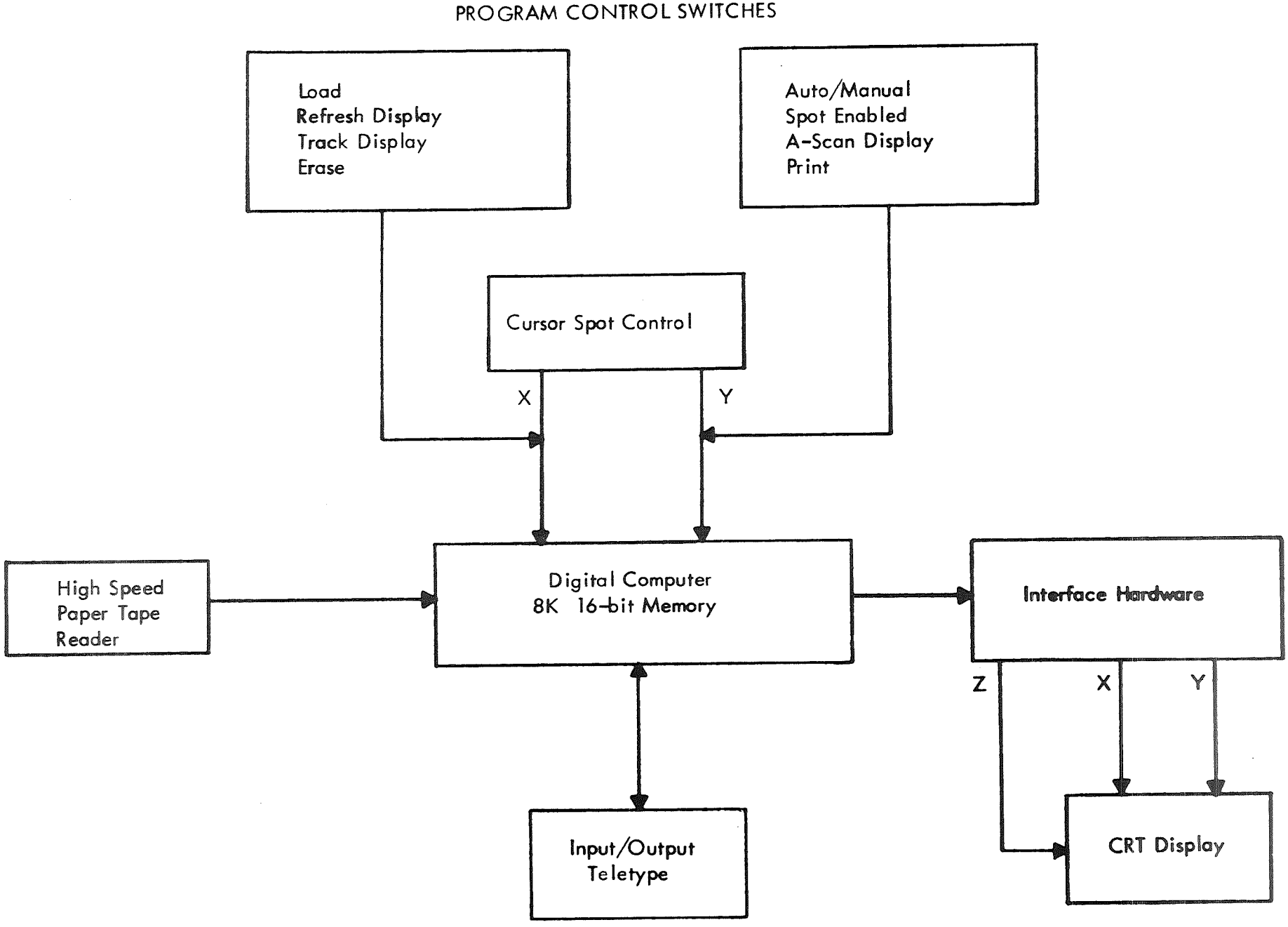

FIGURE 2-1. SIMULATION SYSTEM CONFIGURATION

spot control mechanism and program control switch panel is figure 2-9 at the end of this section.

Referring again to the functional block diagram, the simulation system consisted of a 16-bit, single address digital computer with 8000 words of core memory, a high-speed paper tape reader for program and data input and a teleprinter unit for input/output control. The eight program control switches provided a means for operator control of the various displays and simulator functions.

The interface hardware, between the computer and the CRT display, converted the digital signals from the computer to appropriate X-Y deflection voltages for the cursor spot on the CRT, and provided the raster for the ionogram image. It also provided the decoding logic for the compressed data from Refresh Store, which was then converted to an analog signal to modulate the Z-axis (intensity) of the CRT.

The following CRT displays were implemented:

a. Ionogram image from Refresh Store

b. Cursor Spot under Operator Control

c. Track Display of Data Manually Input from the Cursor Spot Position.

d. Track Display of Data Correlated from Pulse Store with Reference to the Cursor Spot Position.

e. Three A-Scan Lines Displayed to the Right of Ionogram Picture

A detailed description of the software programs used to generate the compressed data for the Refresh Store is given in the appendix. Since the available memory in the computer was limited, certain liberties were taken in the way the data was edited, to provide an adequate ionogram picture but yet leave enough memory for buffer stores and the display program.

2.2 IONOGRAM DISPLAY

The CRT screen size used in the simulator was 18 x 24 cm. The ionogram picture was displayed in a manner which was essentially the electronic equivalent of a film ionogram. The sweep started in the upper left hand corner and was incrementally stepped downward, one element position at a time, until the first line was completed. The spot then returned to the top of the second line and the stepping sequence repeated, etc. At each element position, the beam current was controlled by the value of a 3-bit gray scale word. The display program execution speed was such that approximately five complete pictures or frames were reproduced per second. From an operational standpoint, it would be desirable that the repetition rate exceed the flicker threshold of the human eye, and this should be readily achieved, in most instances, in a final system. The display speed was limited in the simulated system because each output transfer from refresh memory store had to be executed as a separate machine instruction. (The computer was not equipped with a buffered I/O channel.)

2.3 GRAY SCALE

The gray scale of a black and white picture relates to the distinguishable or meaningful shades of gray that can be displayed. The number of gray scale levels selected for use in the project simulation tests was seven plus black. Each gray scale level was represented by a three-bit binary number with 000 = black and 111 = full white. The gray scale levels for echo pulse data were selected to be approximately equally spaced on a logarithmic amplitude scale. A qualitative evaluation of gray scale requirements leads to the conclusion that a seven-level gray scale is really more than can be utilized effectively. The number of gray scale levels required need only be sufficient to produce a reasonable ionogram picture. In the final system, three gray scale levels plus black is considered to be entirely adequate. This can be represented by a two-bit binary number with 00 representing black and 11 representing full white. In the ionogram picture, echo pulse amplitude is represented by the relative brightness of each picture element. It is doubtful that more than three gray scale levels can be distinguished on good filmed ionogram pictures. Much more information is contained in the digitized A-scan data so that peak, leading edge, or trailing edge information can be obtained when desired either by computer program or by operator selection using the A-scan display shown to the right of the ionogram picture on the CRT display, shown in the photograph at the end of this section. The A-scan display is discussed in more detail later in this section and in section IV.

In order to allow complete freedom of investigation, without restraints that otherwise might impose restrictions, the original video data was digitized from an Alouette II analog magnetic tape at the equivalent real-time sampling rate of 128,000 samples per second. The resulting digital tape format was dictated by an existing analog-to-digital data conversion system that was available.

The amplitude range of the data was approximately $\pm$1000 counts with a mean video baseline at -57. The eight-level gray scale conversion was made linear in log amplitude as shown by the tabulated boundary values.

Relative Pulse Amplitude	Gray Scale Code
990	
	7
663	
	6
441	
	5
286	
	4
189	
	3
106	
	2
56	
	1
20	
	0
-57	

The display oscilloscope horizontal and vertical deflection amplifiers, as well as the intensity control, were driven from digital-to-analog converters (DAC). The operands for these three DAC's were loaded from the computer in a compressed format. Peripheral logic converted the compressed data to forms compatible with the DAC's.

The compressed data word format for Refresh Store is shown in figure 2-2. The five different types of words are identified by the four-bit code in the first four bit positions. These are identified in the figure by octal notation.

1) X-word A-scan will be described in the section on A-scan display.

2) X-word, Frame Start was the first word in the Refresh Store and caused the display to start on scan line no. 1.

3) Y-word, Direct Skip and Increment X, was always the last word on each line. This word advanced the X address register to the next line and reset the Y position to minimum range.

4) Y-word, Incremental Skip, was used where there was gray scale level redundancy in a succession of picture elements. If a sequence of elements along the same line remained at the same gray scale level, this Y-word specified the Y address at which the gray scale level changed.

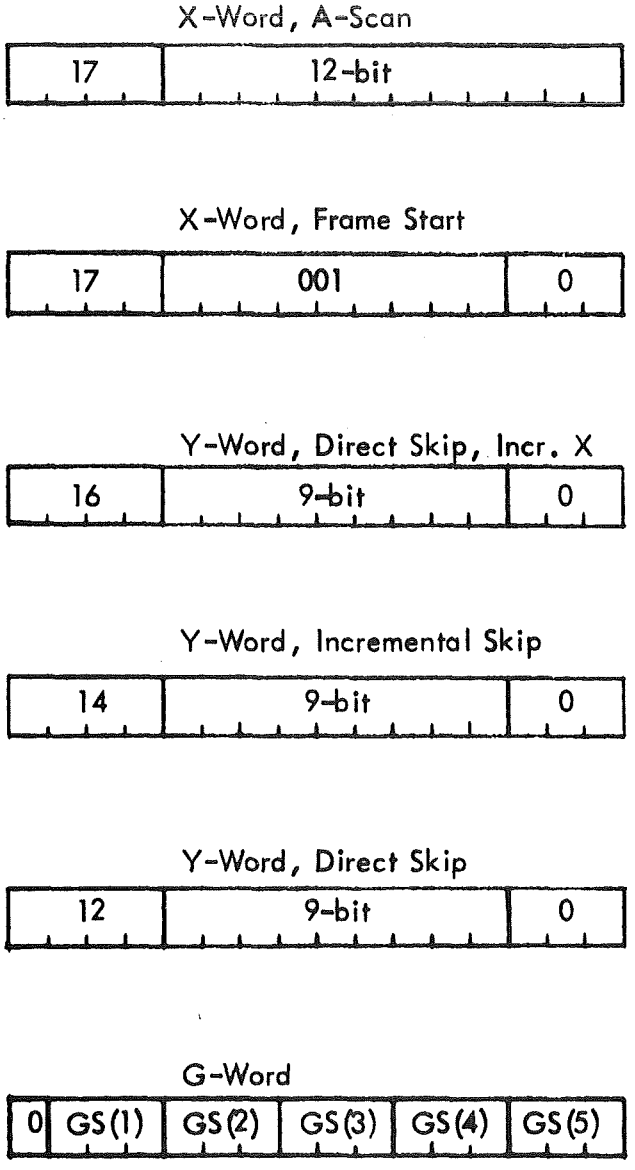

FIGURE 2-2. COMPRESSED DATA WORD FORMAT

5) Y-word, Direct Skip, was used where a sequence of elements on a given line had a gray scale level equivalent to zero. Since the spot was not visible at the zero gray scale level, it was not necessary to increment the spot for each element position.

6) The G-word contained five 3-bit gray scale words (GS-words). The individual GS-words were read out sequentially by the interface hardware which simultaneously incremented the Y address register each time a GS-word was read out.

The digital representation of the ionogram picture was made up of combinations of these six types of words.

The Incremental and Direct Skip Y-words provided a certain amount of data compression which amounted to about 15 percent in the particular portion of the ionogram that was used in the simulation. This is not a particularly large compression factor, but with only a 8K memory in the computer, this factor was quite significant.

Data compression was structured on a line basis, and was not carried over from one line to the next. The Refresh Store word structure was computed on a CDC-6600 Computer using program DISPGEN, which is described in the appendix.

Memory allocations for the simulation program and buffer stores for the project computer are shown in figure 2-3. The Refresh Store was divided into two buffers of 2740 words each, called BUFA and BUFB. This was done initially in order to implement interlaced scanning. The functions of the remaining display buffers will be discussed in the sections which follow.

2.4 CURSOR SPOT

The cursor spot is essentially a pointer which enables the operator to identify, to the computer, any element position in the ionogram picture raster. Each element position in the X-Y plane of the ionogram picture raster has a discrete address X (line number) and Y (element number from zero range). Each line (X) has associated with it a radar pulse frequency which is known when the frequency calibration marker information for a given ionogram has been processed by the computer. In a similar manner, the zero-range time of each line is known from the time code which is played back with the video data. For the operator to identify any element position to the computer, she needs only to adjust the X-Y coordinate position of the cursor spot until it is located where she wants it. When enabled, the cursor spot represents the coordinate position of a data point h'(f) input by the operator.

An X-Y position control system for the cursor spot was the one selected for simulation. X-Y position control is one in which the position of the cursor spot is proportional to the position of a hand-controlled stylus having two degrees of freedom in the X-Y plane. The X-Y position control system was implemented using

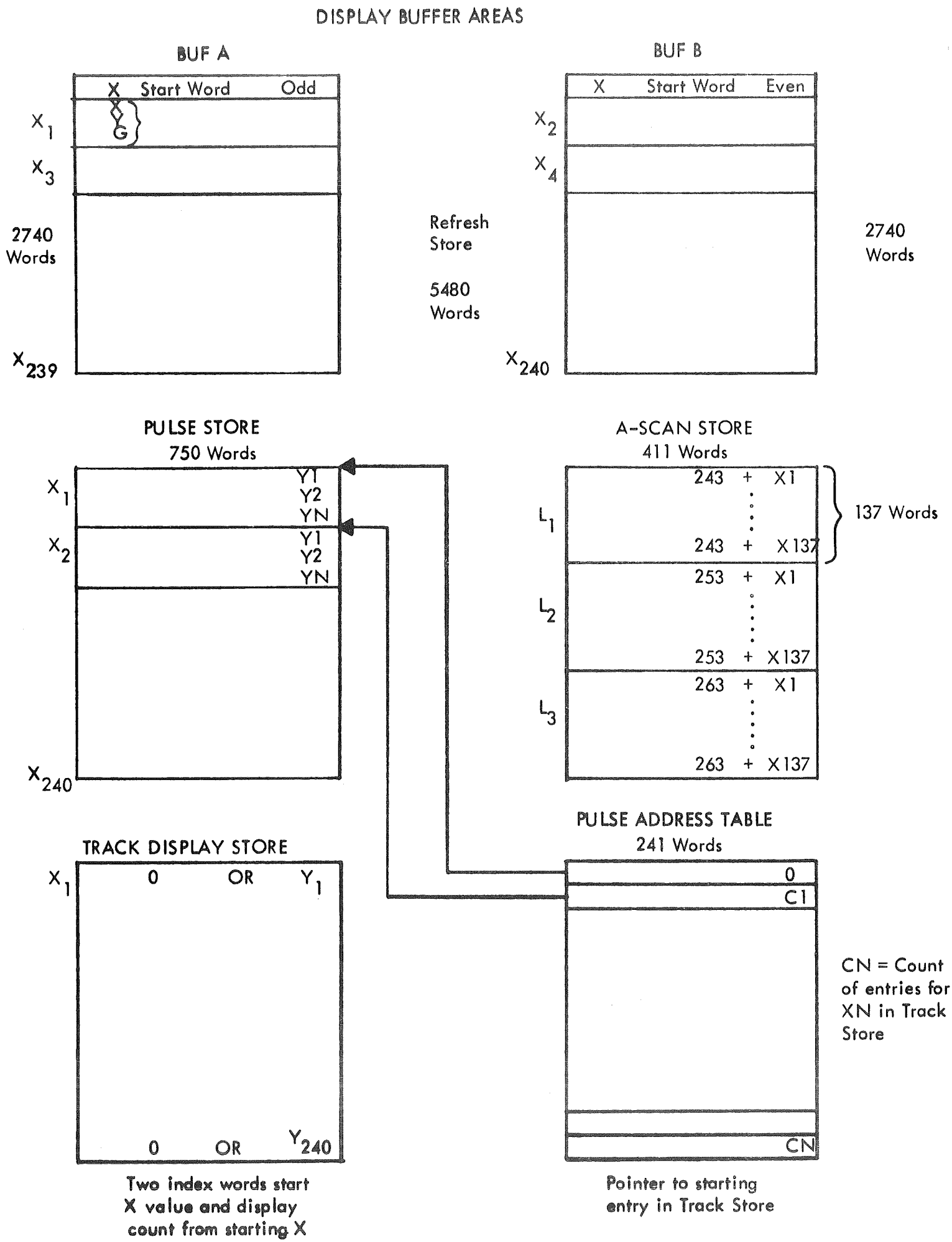

FIGURE 2-3. DISPLAY BUFFER AREAS

a modified X-Y plotter mechanism. The control knob (stylus) was mounted on the pen carriage to provide a means for controlling the position of the contactors on the slide wires. The servo motors in the plotter mechanism were removed in order to reduce the force required to move the mechanical linkage.

The functional block diagram of the cursor spot position control system is shown in figure 2-4. With dc voltages across the slide wires, the X and Y analog output voltages were proportional to the position of the stylus. These voltages were digitized and input to the spot position registers in the computer, which were linked to the display program to display the spot once per frame. The scale factor was adjusted so that the ratio of stylus travel to spot travel was approximately 1:1.

No calibration of the cursor spot control system is required since the position of the spot and the stylus are only relative. The operator simply moves the stylus until the spot is where she wants it to be on the CRT display. The feedback loop is closed through the eyes and hand of the operator.

Since the cursor spot is displayed in the coordinate system of the ionogram picture, it must be on one of the elements on a line in the picture. It is impossible for the spot to be positioned half-way between two elements or between adjacent lines. The spot is essentially the same size as a single picture element, but it stands out clearly because of its brightness. It is very easy for an operator to position a spot on

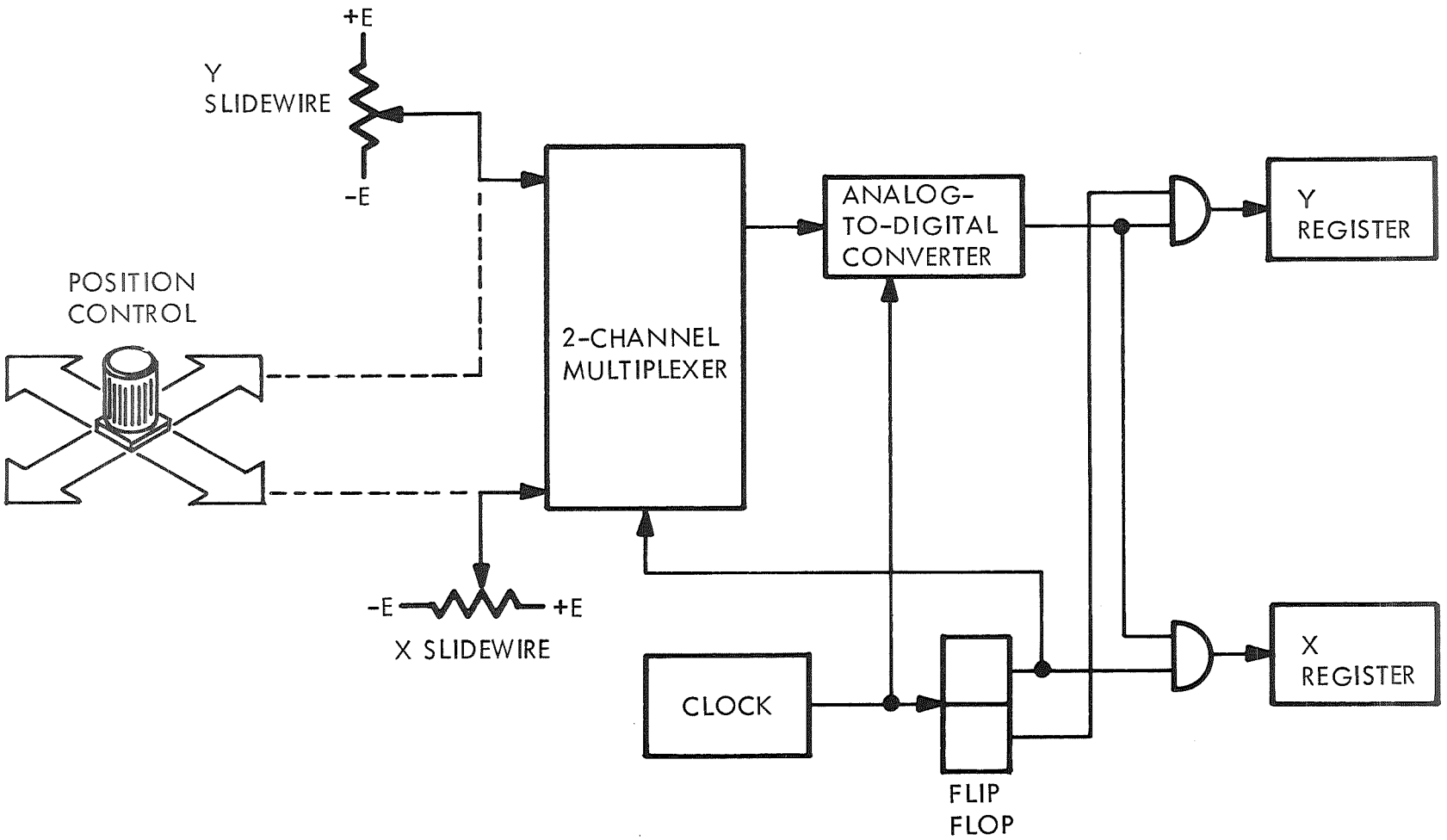

FIGURE 2–4 FUNCTIONAL BLOCK DIAGRAM CURSOR SPOT POSITION CONTROL

the exact picture element she desires, and there is nothing to obstruct the view as there would be if a light pen were used.

In a final system, it is recommended that the stylus table be inclined from 20° to 30°, rising upward from front to back, with the CRT screen directly above it. This will provide a comfortable and natural "writing desk" position for the operator's arm and hand, with the CRT screen and stylus as close together as possible. When an echo trace is interpreted, the arm and hand execute a coordinated movement to sketch the outline of the trace under the guidance of optical feedback through the operator's eyes. The operator moves the stylus to cause the cursor spot to follow, for instance, the X-trace displayed on the CRT.

In the simulation system, the manually selected spot addresses for each line were entered into a memory area entitled Track Store buffer. Selected data points from Track Store represented a set of $h_x'(f)$ data points suitable for subsequent $N_x(h)$ computation. Data from Track Store could also be used as the correlation model for data from Pulse Store, so that all of the echo pulses that belonged to the set called "X-trace" could be located by a Pulse Store correlation subroutine.

2.5 TRACK DISPLAY

The Track Store, in the simulated system, used a buffer area in memory arranged to store an array Y(K), K = 1, 2,...., 240, where Y(K) was the echo pulse range and

K was the ionogram line number. Data points could be entered into Track Store in two different ways:

1) With program control switches TRACK DISPLAY, MAN, and ENABLE, on, values of Y(K) representing the coordinate position of the cursor spot were entered into Track Store. Only one data point per line could be stored.

2) With AUTO, ENABLE and TRACK DISPLAY program control switches on, pulses from Pulse Store within a window centered on the cursor spot position were transferred to Track Store.

In manual mode, after a preliminary track had been stored, any data points in Track Store could be readily changed by moving the cursor spot to the corrected position and momentarily setting the program control switch to ENABLE. This action stored a new value, Y(K).

In the simulation system, momentarily pressing program control switch ERASE cleared the entire Track Store in preparation for entry of new data. The entry point to the Track Store for display was the line number, K, on which the first data point was entered in Track Store after the ERASE switch had been actuated. Data values on line numbers less than the display entry point were not displayed. This limitation proved to be inconvenient and is not recommended for the final system. Once a set of data values was entered into Track Store, the track display, which appeared to be superimposed on the ionogram picture, could be turned on or off by means of program control switch TRACK DISPLAY.

When the Track Store buffer was linked to the display program, the coordinate positions represented by the data in Track Store were displayed in sequence following the completion of an ionogram frame. Track display on the CRT appeared as a set of data points superimposed on the ionogram, as shown in figure 2-15 at the end of this section.

2.6 CORRELATION OF DATA FROM PULSE STORE

The data in Pulse Store represented the coordinate positions of all candidate pulses in the 240 lines of the ionogram display. The data in Pulse Store was a two dimensional array of the form

$$P(J,K),\ J = 1,\ 2,\ 3,\ \ldots\ ,\ N$$
$$K = 1,\ 2,\ 3,\ \ldots\ ,\ 240$$

where P(J,K) was the equivalent range of a pulse on line K and J was the pulse number of N pulses on line K.

Values for P(J,K) were computed on a CDC 6600 Computer using program CODEGEN. This program and Pulse Store are described later in the Simulation Software Appendix. Data for Pulse Store was loaded into the simulation computer memory from paper tape using the high-speed paper tape reader.

In the proposed final system described in section IV, there is no need for a Pulse Store per se. Instead, only those pulses required will be located from A-scan data in disc memory. The range of a pulse peak near a reference data point, represented by the cursor spot

position in manual mode, or from h'(f) or $\overline{h'(f)}$ data point in Track Store in automatic mode, would be determined as follows:

1. Read A-scan line, transferring to core memory data values 100 km either side of the reference data point.
2. Call digital pulse detector subroutine to locate and determine the range of any pulse(s) in the data from (1).
3. Compare pulse range(s) with window centered on the reference data point. Select range of pulse nearest the reference data point that falls within the window.

When there is a gap in a trace, there will be no corresponding data in Pulse Store, so that when in the AUTO mode, the value of Y for a given line, K, is arbitrarily assigned the value 0 in Track Store. In the simulation system, these missing data points were filled in by changing the program control switch to MAN (manual), positioning the cursor spot on the desired data point and transferring its coordinate position to Track Store by closing the ENABLE switch.

In a final system, it would not be necessary to determine accurately $h_x'(f)$ data points for each line. Certain selection rules would be invoked for choosing the frequencies at which data points $h_x'(f)$ were to be selected. Assuming that from 15 to 25 data points are to be scaled for the X-trace, it would be necessary to scale $h_x'(f)$ accurately only on the particular lines representing these frequencies.

2.7 OFFSET TRACK DISPLAY

On the first simulation trial, the spot track was displaced downward by 0.25mm so that the track display was not superimposed exactly on element positions of the ionogram. It was found that this was not necessary, however, because the brightness on the CRT screen is a function of not only beam current, but also the dwell time. The track display was brightened by displaying each data point from Track Store approximately three times as long as an element in the ionogram picture was displayed. Since there were relatively few data points in the track display, the increased dwell time for the track display did not significantly change the repetition rate of the total display.

Another idea that was tried as a way of identifying separate elements of the track display, was to cause the track display to blink on for ten frames and off for four frames. A track display that blinked was somewhat distracting, and was found to be unnecessary because the increased brightness of the track display over that of the ionogram picture made it stand out very clearly.

In the final system there would be separate Track Stores for the X-trace, O-trace, Z-trace, and the corresponding inverse traces that could be selected by the operator in any combination she desired.

2.8 A-SCAN DISPLAY

When an interpretation of the X-trace is scaled manually, it is not always possible to identify the peak of the pulse by looking at the ionogram picture. The pulse

amplitude information is on the original magnetic tape, and this would be digitized and stored in memory for A-scan display. In the simulated system three A-scan lines were displayed to the right of the ionogram picture in order to demonstrate how pulse amplitude information could be presented conveniently to the operator.

It is anticipated that under most circumstances the operator will be interested in only a portion of the ionogram view field, and may desire to expand that interesting portion for convenient viewing. The console controls are arranged so that the operator can expand any segment of the view field to provide a much higher resolution display. For example, figure 2-5 "Expanded Ionogram View Field," outlines an area that the operator might wish to expand. The resultant expanded display is shown in figure 2-6, "Expanded Ionogram Display With A-scan Augmentation". As shown in this sketch the operator may also call for an A-scan display in conjunction with her operator cursor. The operator cursor is a bright spot that may be maneuvered about the face of the display by means of a stylus control. In the combination ionogram and A-scan display, the A-scan represents the line selected by the cursor as well as the preceding and following lines. See right-hand sector of the drawing.

This cursor technique thus allows the operator to project her opinions into the ionogram interpretation. It is expected that in certain modes the system will properly identify the echoes of interest. However,

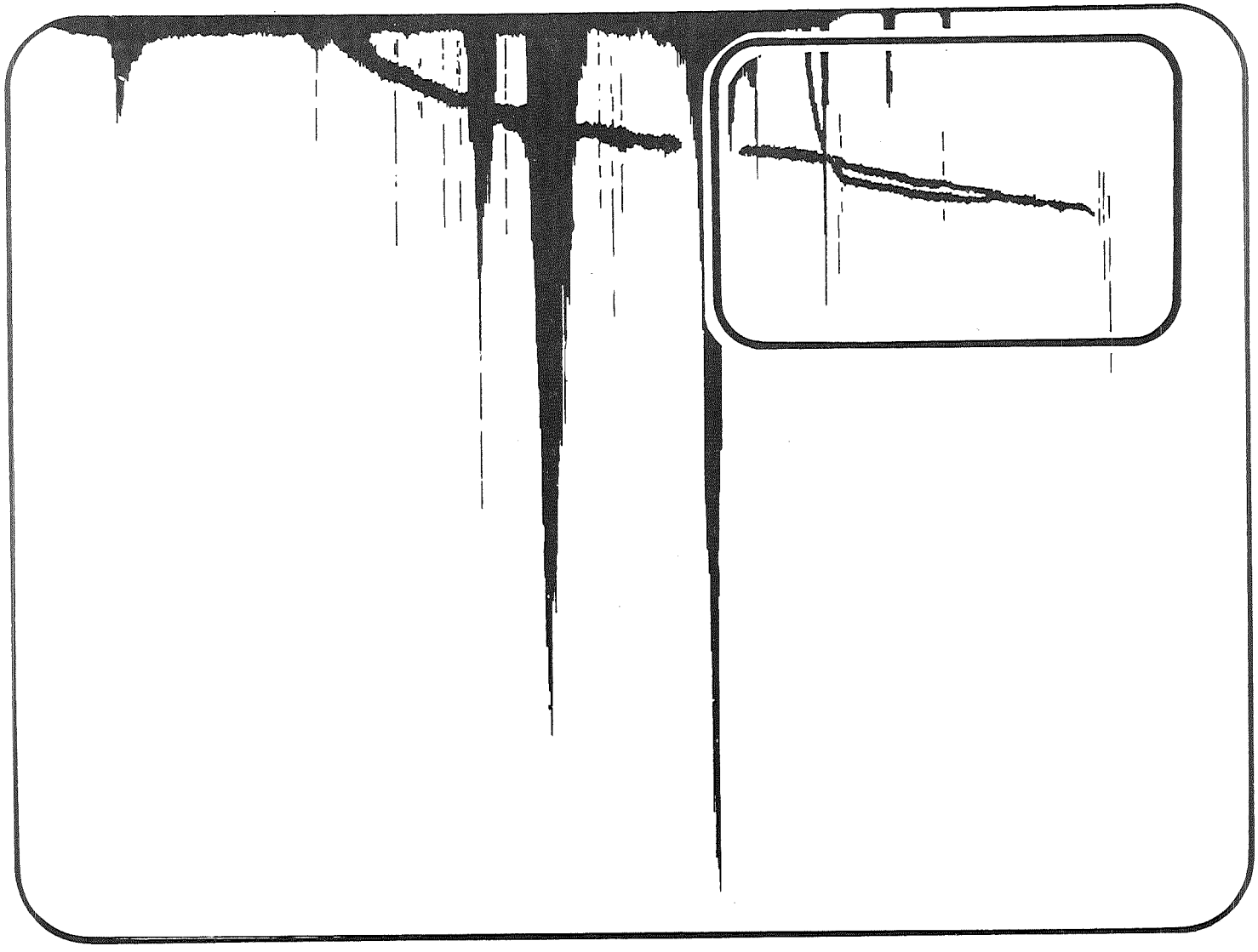

FIGURE 2-5. EXPANDED IONOGRAM VIEW FIELD

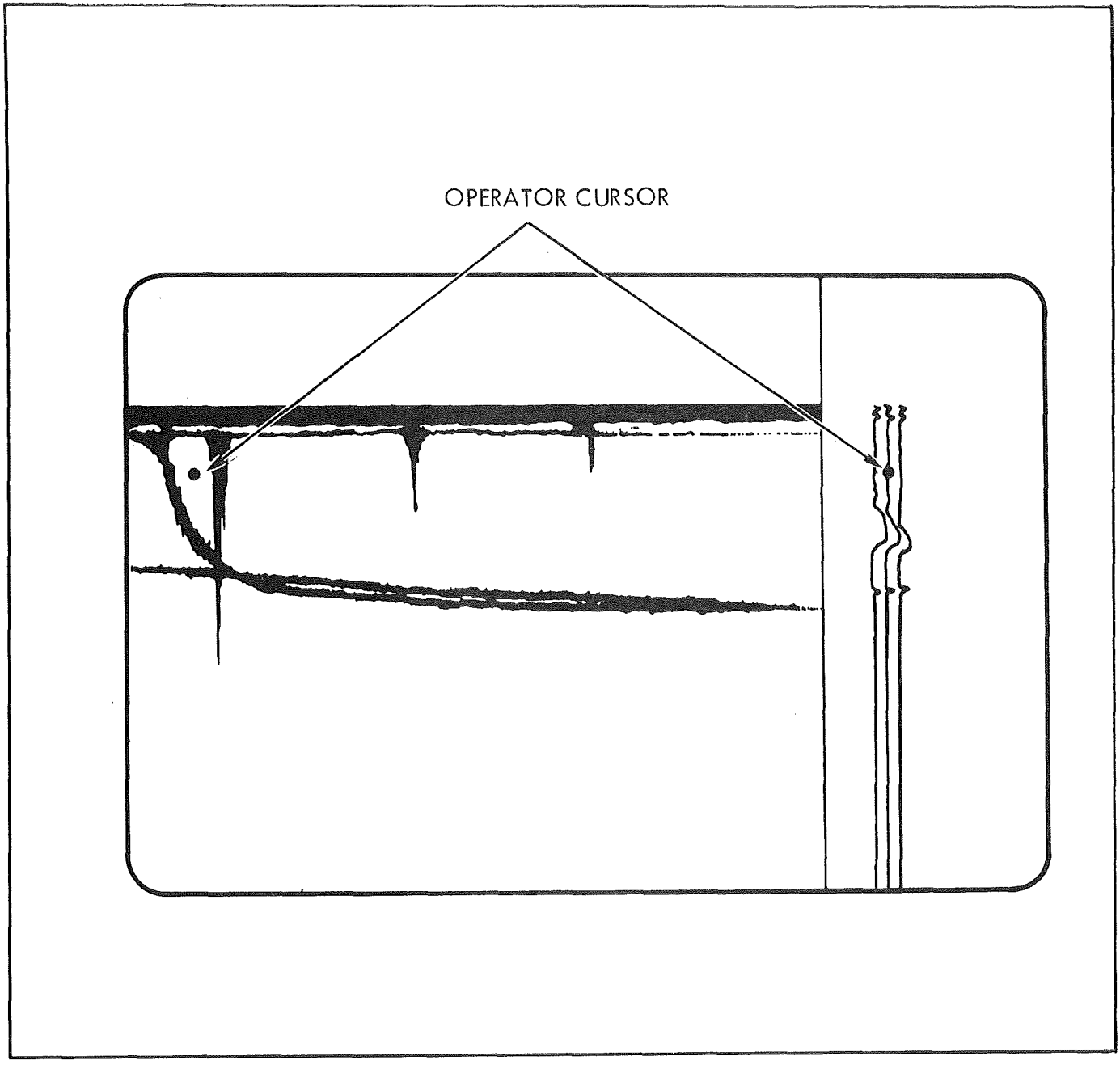

FIGURE 2-6. EXPANDED IONOGRAM DISPLAY WITH A-SCAN AUGMENTATION

in those cases where the system makes an improper conclusion, it is necessary that the operator intervene and provide what only a human can provide, namely the factor of complex judgment.

A photograph of the CRT with A-scan display is shown in figure 2-14 at the end of this section. The A-scan display is under control of the cursor spot. The middle A-scan line in the display shows the amplitude information on the line on which the cursor spot is positioned. The other two A-scan lines show the amplitude information on the line preceding and the line following the middle A-scan line.

In the final system, the A-scan display will change as the position of the cursor spot is changed from one line to another so that the middle A-scan line always shows the amplitude information relating to the line on which the cursor spot is positioned. Because of limitations in the memory of the simulated system, it was not possible to change the A-scan display very easily. The data for A-scan display was loaded from paper tape for specified line numbers.

A-scan data for the simulation was processed from the original raw digital data on a CDC 6600 using program CODEGEN, which is described under simulation software in the appendix. The resulting X-word, A-scan computer word format was shown previously, in figure 2-2. The special X-words for A-scan display were read out and displayed sequentially to produce the

desired amplitude profile. Maximum A-scan deflection amplitude was approximately 10 mm, while the incremental resolution was 1/8 mm. Vertical deflection was implemented by incrementing the Y-address register by one as each X-word was read out.

The range position of the cursor spot is also superimposed on the middle A-scan line and is arranged to follow the amplitude contour of the pulse as the cursor spot is moved along the Y axis. By this means, an operator could position the range pointer spot on the A-scan trace at the peak of the pulse or on the leading edge or trailing edge as she desired.

When a complex high altitude ionogram is being scaled, the additional amplitude information provided by the A-scan display will be very useful.

2.9 EFFECTS OF LIMITED FREQUENCY RESPONSE

The large-screen oscilloscope, in the simulated system, used a CRT with magnetic deflection. The frequency response of the amplifiers and the corresponding deflection yokes was down approximately 3 db at 50 kHz.

This introduced a delay such that the spot lagged behind the correct element position by approximately six increments along the Y axis, which is equivalent to approximately 35 km in range. The cursor spot and track display

were offset six increments along the Y axis in order to compensate for this delay. Compensation of this type for limited frequency response is difficult to calibrate for all cases and is not considered acceptable for a final system. Further, it is not desirable to reduce the scanning rate in order to reduce the effects of limited frequency response in the deflection circuits, because low picture repetition rates are somewhat distracting to look at for any length of time, and would cause tiring of an operator.

Large screen display scopes with electrostatic deflection, having wideband response on the X, Y, and Z axes, are available on the market. A display of this type is recommended for the final system in order to avoid the problems inherent in a limited frequency response magnetic deflection oscilloscope.

2.10 ALTERNATE MAN-MACHINE COMMUNICATION MEDIA

The preceding paragraphs have described a real-time ionogram display console simulated in an operational mock-up. This study project simulator was equipped with a movable spot type cursor controlled by an X-Y coordinated stylus. It is of interest to examine an attractive alternate approach using conventional light pen technology.

A photo cell triggered interrupt arranged as a so-called "light pen" is an attractive device for communication

from man to machine. The principle of operation is simple. A hand-held photo cell device is positioned by the operator at an interesting spot on the face of a computer-controlled CRT display. During the next display refresh scan, the spot facing the photo cell sensor pickup is excited momentarily in the normal course of regenerating the display. When the particular spot of interest is the instantaneous target for the sweeping CRT beam, the high-speed photo cell output experiences a step transition. This pulse is coupled to the CRT refresh controller advising that the operator is interested in the display element corresponding to the CRT beam position at this particular instant. It is a straightforward task then for the display control computer to relate the light pen position with the corresponding parameter displayed on the CRT at the pen location--such as radar range to a particular approaching aircraft, apparent height to observed ionosonde echo, sonar echo delay, etc., depending upon system application.

A variety of light pens are available on the commercial market. Some employ a fibre optic bundle to conduct the CRT screen light to a nearby photo cell; others employ a photo cell type transducer in the hand-held unit without recourse to fibre bundles. For improved resolution, optics have been incorporated in special units to enhance focusing.

The advantages of the light pen are:

Low Cost

Not only is the light pen and its associated electronics inexpensive, but further, the link to the CRT controller is simply the concurrent observation of the present CRT beam position and a

pulse from the hand-held light pen. Therefore, the interface equipment is also low in cost and involves neither complex nor precise analog measurements, shaft encoder wheel interpretation, etc.

Natural Gesture

Selecting a point of interest may be as natural as pointing a pencil.

No Mechanical Moving Parts

Historically, "all-electronic" apparatus, such as a light pen assembly, provides very high reliability in comparison with alternate schemes involving mechanical units.

The Limitations of Light Pen are:

Resolution

In a topside sounder system application, 4000 kilometers of apparent height may be represented by about 200 mm on the CRT screen; i.e., 20 km/mm. The separation between a particular echo trace segment of interest and other nearby traces (or noise appearances) is oftentimes less than 20 or 30 km. (It is commonplace to encounter a trace of interest that gradually merges with another interfering trace.) Accordingly, a light pen should have acceptable resolution to ignore, say, a very bright X-trace that appears within 1 or 2 mm of an interesting but comparatively dim O-trace. Another example where resolution requirements become paramount is where field aligned echos produce a family of near-parallel traces and only one trace is to be scaled. The

interesting trace at times is less bright and distinct than other, nearby and converging traces.

The typical "advertised" resolution of commercial light pens is 3 to 6 mm. Some specifications presume careful preadjustment and equal intensity adjacent spots for resolution performance testing.

Resolution problems are not considered unsolvable. For example, the interesting portion of the screen might be expanded to increase the separation between interfering traces. Alternatively, special optics might be contrived to help reduce interference from distracting, nearby brilliant light patterns.

Probe Head Size

Most light pen probes are more than a centimeter in diameter and tend to mask the trace of interest. During the study simulation, there were typical cases observed (on thin line ionograms), employing expanded displays, where clearly defined traces could be identified to within $\pm$0.5 mm. However, it is awkward to position accurately a comparatively bulky probe within these tolerances, when the pen itself obscures the operator's view of the point of interest. A secondary problem is the usual requirement that the probe must be held exactly perpendicular to the screen during precise scaling operations.

Annotating a Void

Inherently, a light pen requires that a point of interest must be illuminated in order to be selected. However, traces are oftentimes discontinuous and a point of particular interest may be in a dark void. A conventional light pen arrangement is unable to designate such a point in a "blank" region.

A number of remedies are possible for this shortcoming. One scheme is to position the pen on the blank point of interest and then cause the display controller to scan temporarily the entire screen with a background raster in order to trigger the light pen. Another scheme is to enter a special mode where the beam current is intensified in the region of the light pen. Thus, the operator could select any convenient illuminated spot to initiate the operation, and then "drag" the resultant intensified spot to the particular position of interest via this self-excited procedure. Other, more complex solutions to this fundamental light pen shortcoming involve a continuous low-level background raster superimposed upon the regular display and partially illuminating the entire screen. This approach imposes rather significant bandwidth demands on the CRT display design or requires complicated interlace schemes wherein a low-level full screen raster is substituted periodically in lieu of the regular display.

Summary

The light pen is an intuitive first choice as a man-machine communication media. Given sufficient design time it is very likely that one by one its salient limitations could be overcome. However, some of the solutions have far-reaching interplay with operational procedures and the design of other subsystems. On the other hand, the movable spot type cursor with a coordinated X-Y stylus control offered an unobscured cursor only a fraction of a millimeter in diameter that could be easily and rapidly maneuvered to any point on the screen. The virtues of the cursor spot are:

No practical resolution limitation.

No difficulty positioning the cursor $\pm$0.5 mm.

Cursor spot is never obscured.

No special procedures to select a point in a "blank" region.

No requirement for perpendicular probe positioning.

The cursor control stylus plate may be positioned comfortably as a writing desk with no need to support a pen in the air for hours on end. In the course of the simulation, the cursor technique proved to be entirely satisfactory with operator familiarization encompassing less than an hour.

2.11 "JOY STICK" RATE CONTROL

A rate control system for the movable spot is one in which the direction and rate at which the spot moves depends on the position of the operator's control lever orrjoy stick with respect to its neutral or center position. The joy stick is mounted on a two-axis gimble with separate transducers for the X and Y axes. A functional block diagram of a Rate Control system is shown in figure 2-7. Deflection of the joy stick in the X direction produces motion of the spot at a rate proportional to the angular deflection. The output signal from the X-axis transducer controls a variable rate clock generator which drives an up-down counter. The output of the up-down counter is the digital representation of the X position of the movable spot on the CRT. The Y-axis channel is identical to the X-axis channel and produces motion of the spot at a rate proportional to the deflection angle of the joy stick in the Y direction.

The operator input to a rate control system is quite different from that of an X-Y position system. A rate system is the first derivative of a position control system and requires that the operator effectively integrate the rate control information in order to move the spot from one position to another on the CRT. An operator could certainly learn to control a rate type system but it would likely involve more conscious control of the required action than would be required by an X-Y position control system.

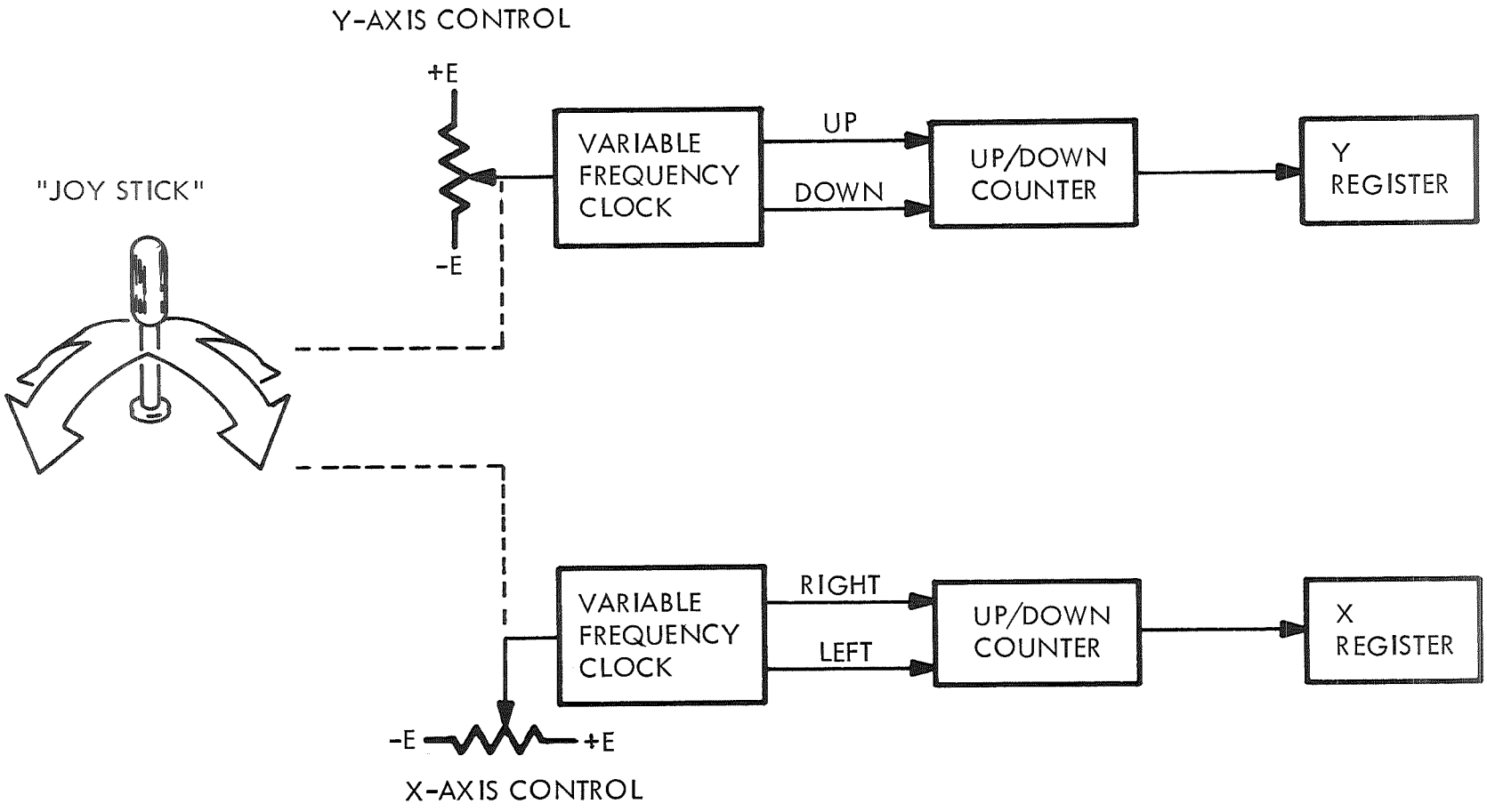

FIGURE 2–7 FUNCTIONAL BLOCK DIAGRAM "JOY STICK" RATE CONTROL SYSTEM

2.12 TRACK BALL, CURSOR SPOT CONTROL SYSTEM

A track ball cursor spot control system is another type of position control system in which the operator can control the position of a cursor spot by rotating a smooth sphere approximately four inches in diameter which is inset in a table with approximately one-third of its diameter above the surface of the table. Separate X and Y transducers sense the rotation of the sphere. This information is digitized and becomes the coordinate position of the movable spot. The operator causes the spot to move by placing the tips of her fingers on the top of the sphere and causing the sphere to rotate in the direction in which the spot is to be moved.

The track ball was developed at Hughes, Fullerton, in connection with a radar data display system for a continental defense system. The track ball was the outgrowth of a detailed human engineering study on cursor spot control. The Hughes, Fullerton plant was visited at the beginning of the study program and provided an opportunity to operate the track ball system and to get the feel of it. The track ball has enough inertia to require a significant force to cause the sphere to rotate. Once rotating, it requires other forces to change the direction of rotation and to stop the sphere. A maneuver was attempted to cause the movable spot to follow a simulated X-trace. It was found to be rather difficult to change continuously the direction of rotation of the sphere as would be required in following the X-trace through the region where the rate of change of slope is maximum. As a result of these tests and comparison with the X-Y position control system, the

latter is considered to be much more desirable for cursor spot control for this application than the track ball system.

2.13 INTERLACED SCANNING

The simulator was initially configured with two Refresh Stores called BUFA and BUFB. The loader program for the project computer selectively loaded the odd-numbered lines into BUFA and the even-numbered lines into BUFB.

These buffers were linked in the display program to produce interlaced scanning. The objective was to display two half-frame pictures at twice the rate at which a full frame picture could be displayed. Unfortunately, the frame rate was so low that the individual half-pictures were seen separately instead of merging into one complete picture. Apparently interlaced scanning can be beneficial if the frame rate is above some minimum, but below this rate, interlaced scanning is distracting and is considered undesirable. In summary, the use of interlaced scanning is not recommended if the amount of picture data and the rate at which it can be processed are such that the picture frame rate is below the flicker threshold of the human eye.

2.14 SIMULATION SOFTWARE

The software written to support the simulation study of the man/machine communication link was divided into two phases. The first phase was the preprocessing phase and the second phase was the loader and display software which was written for the digital computer used in the simulated system. A detailed discussion of the simulation software is contained in the appendix.

2.15 CONCLUSIONS FROM THE SIMULATION

The conclusions drawn from the simulation were not necessarily confined to the man-machine link per se. For example, gathering data for display involved the questions of A-scan sampling resolution, and amplitude measurement accuracy. In order to compare apparent heights of detected pulses with the cursor spot, it was necessary first to consider the feasibility question of a practical pulse detection scheme for overlapping pulses - etc.

The more significant conclusions were:

1. The Cathode Ray Tube display is an entirely adequate substitute for the filmed ionogram, particularly when reinforced with concurrent A-scan displays.

2. It is practical to hold conversational exchanges between an operator and the processor via a CRT, keyboard (or switch-panel) and a cursor spot control.

3. Concurrent display of A-scan data is a great aid when selecting echo pulses.

4. Television style interlacing of alternate even and odd display lines seems of little value.

5. The CRT large signal deflection bandwidth should be greater than 2 MHz. Beam current modulation bandwidth should exceed 10 MHz.

6. Four shades of gray produce an adequate ionogram image.

7. 200,000 image elements are adequate to present an ionogram on an 18 cm x 24 cm display.

8. Practical data compression techniques can be devised to store a complete ionogram image with less than 32,000 bytes of core memory.

9. Display refresh rates should be greater than 10 per second.

10. A-scan samples with 5 km spacing are adequate for the processing requirements.

11. A $\pm$1% uncertainty is acceptable accuracy for A-scan data amplitude measurements, i.e., 64 levels from slightly below video baseline to maximum echo pulse peak (bandedge) is suitable measurement resolution.

12. A practical hardware design exists for a synchronizer and demodulators to accommodate accelerated playback up to four times real-time.

13. Suitable interlocks are required to protect the CRT screen from being damaged if scanning fails or stops.

14. 18 cm x 24 cm is an adequate screen size for the display CRT.

15. An offset track display is unnecessary.

16. A blinking track display is undesirable.

2.16 SIMULATOR PHOTOGRAPHS

A photograph of the Study Project Simulator is shown in figure 2-8. The digital computer and its control panel are in the dual cabinet at the right. On the table in front is the Teletype unit and paper tape rewind machine. The interface hardware, high-speed paper tape reader and ADC for the cursor spot control system are located in the cabinet to the left of center. The CRT display and controls are on the far left.

A close-up view of the Simulator CRT display, cursor spot control mechanism and program control switches is shown in figure 2-9. The control switch functions from top to bottom are as follows: ERASE, TRACK DISPLAY, REFRESH DISPLAY, LOAD, PRINT, A-SCAN DISPLAY, SPOT ENABLE, MANUAL/AUTO.

The ionogram shown in figure 2-10 is an enlargement of Alouette II Film Ionogram 20 50 66 049 1626 40 (Ottawa 966). This ionogram was processed from analog magnetic tape for the simulation study.

The ionogram in figure 2-11 is an enlargement of a portion of Film Ionogram '#1626 40'.

Figure 2-12 is a photograph of the Simulator CRT display showing ionogram '#1626 40'. Only the even-numbered lines are shown in order to display a 16-second portion of the ionogram with only 240 lines. The display shows only that portion of the ionogram between 100 km and 800 km. The cursor spot can be seen in the gap in the O-wave trace.

Figure 2-13 is a photograph of the CRT display showing an eight-second portion of ionogram '#1626 40' with both the frequency and range scales expanded. Each of 240 consecutive lines in the ionogram are displayed in this picture. The lines appear curved towards the right of the picture due to the curvature of the CRT. The cursor spot can be seen near the left center of the picture in the gap in the O-wave trace.

The display in figure 2-14 is the same as figure 2-13, except that the augmented A-scan display has been added. The cursor spot can just be seen in the X-wave trace. The pointer spot on the middle A-scan line is at the same range as the cursor spot.

The display in figure 2-15 is the same as figure 2-13 with a track of manually input $h_x'(f)$ data points superimposed on the X-wave trace.

The X-Track Display is shown in figure 2-16. The individual dots on each line are easily distinguished. The minimum vertical spacing of approximately 1 mm represents the incremental resoltuion of the picture elements and, in this simulation system, corresponds to 5.85 km.

The display in figure 2-17 is the same as figure 2-12 with the addition of the three-line A-scan display. The cursor spot on the X-trace did not reproduce well in this photograph. On the actual display it stands out quite clearly.

The display in figure 2-18 is the same as figure 2-12 with a track of manually input $h_o'(f)$ data points superimposed on the O-wave trace. The vertical steps in the track near the lower right represent minimum 5.85 km increments in range.

The display in figure 2-19 is the same as figure 2-18 with an additional track of manually input $h_x'(f)$ data points superimposed on the X-wave trace.

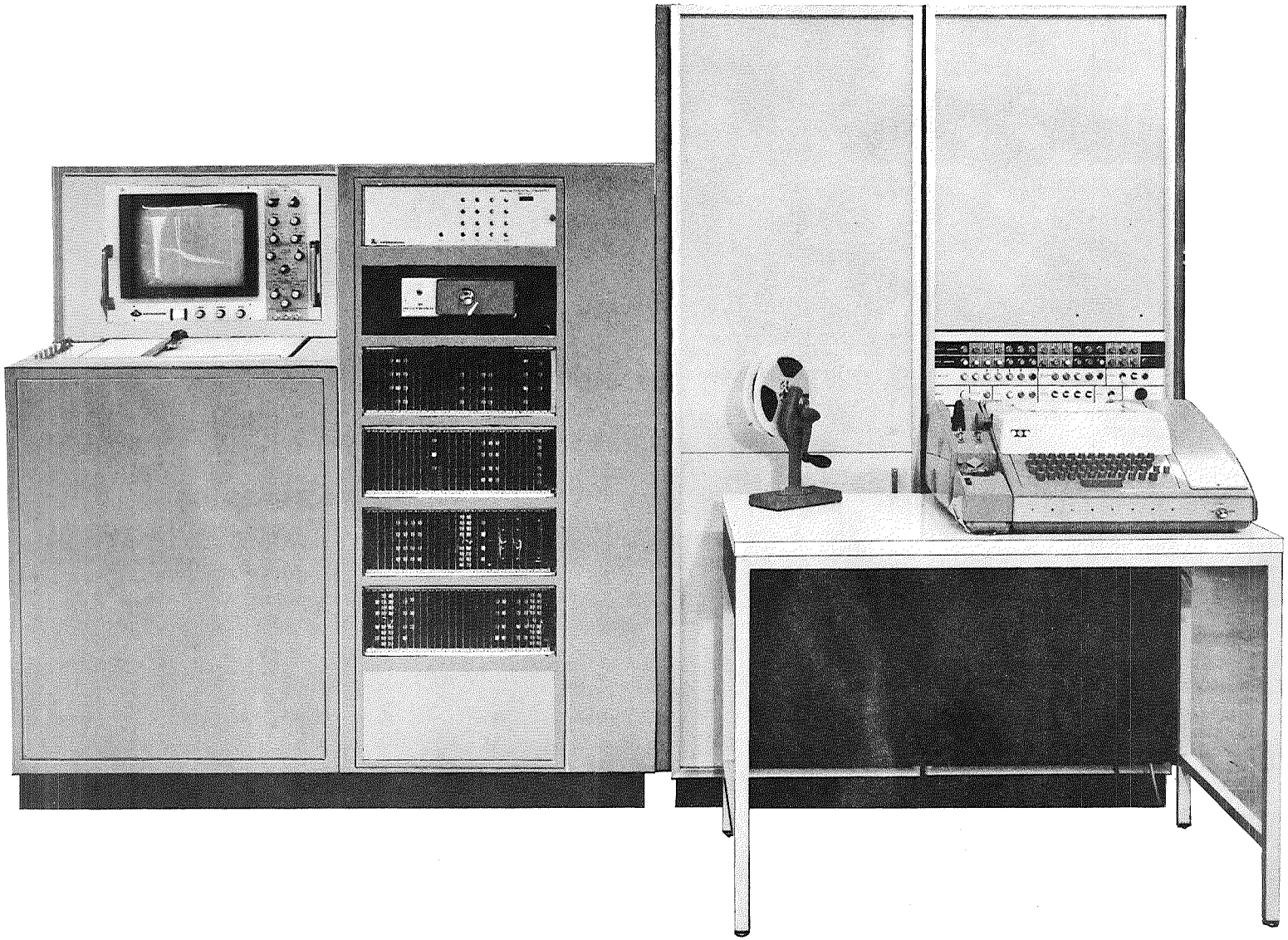

FIGURE 2–8 STUDY PROJECT SIMULATOR–MAN/MACHINE COMMUNICATION LINK

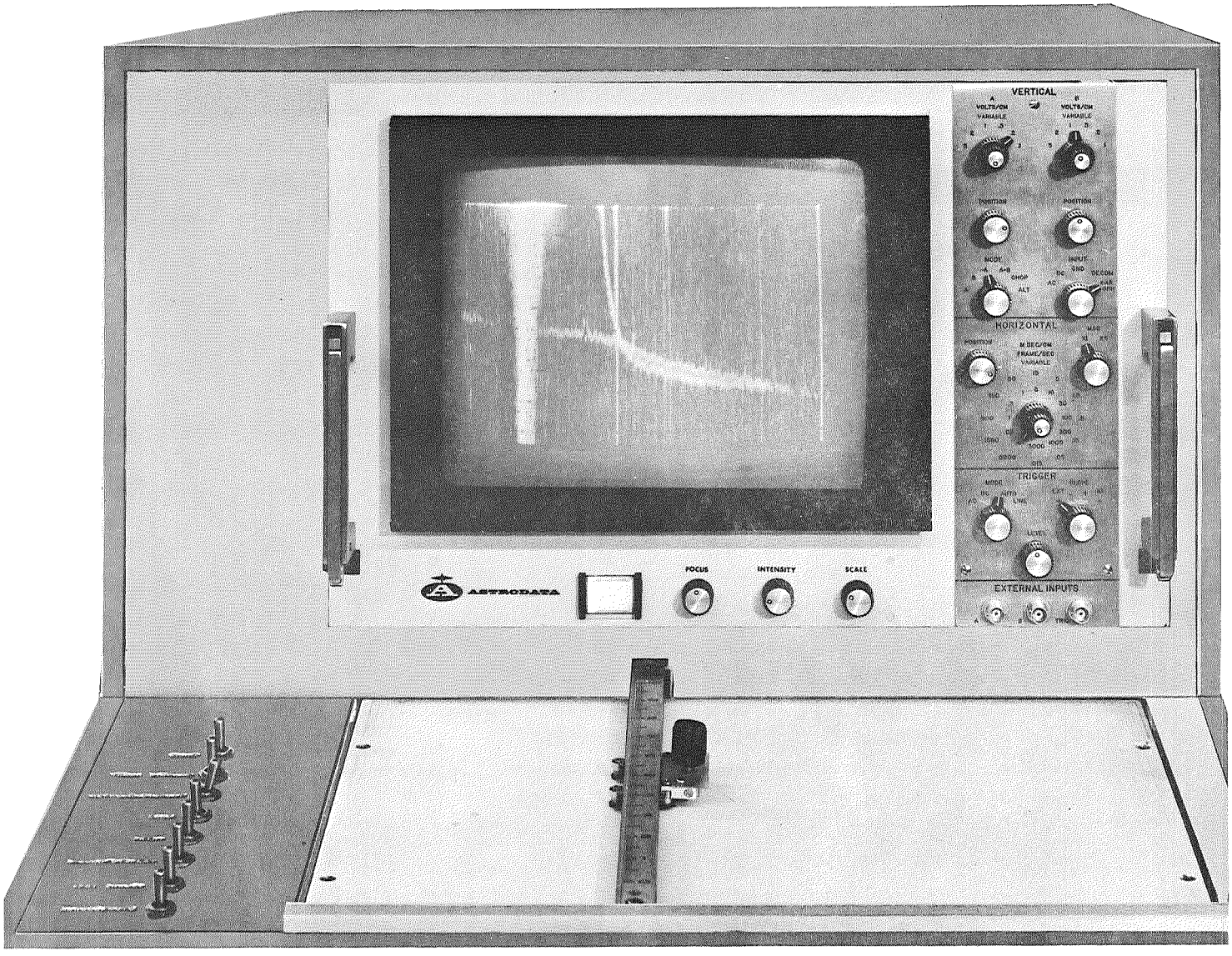

FIGURE 2-9 SIMULATOR CRT DISPLAY, CURSOR SPOT CONTROL MECHANISM, AND PROGRAM CONTROL SWITCHES

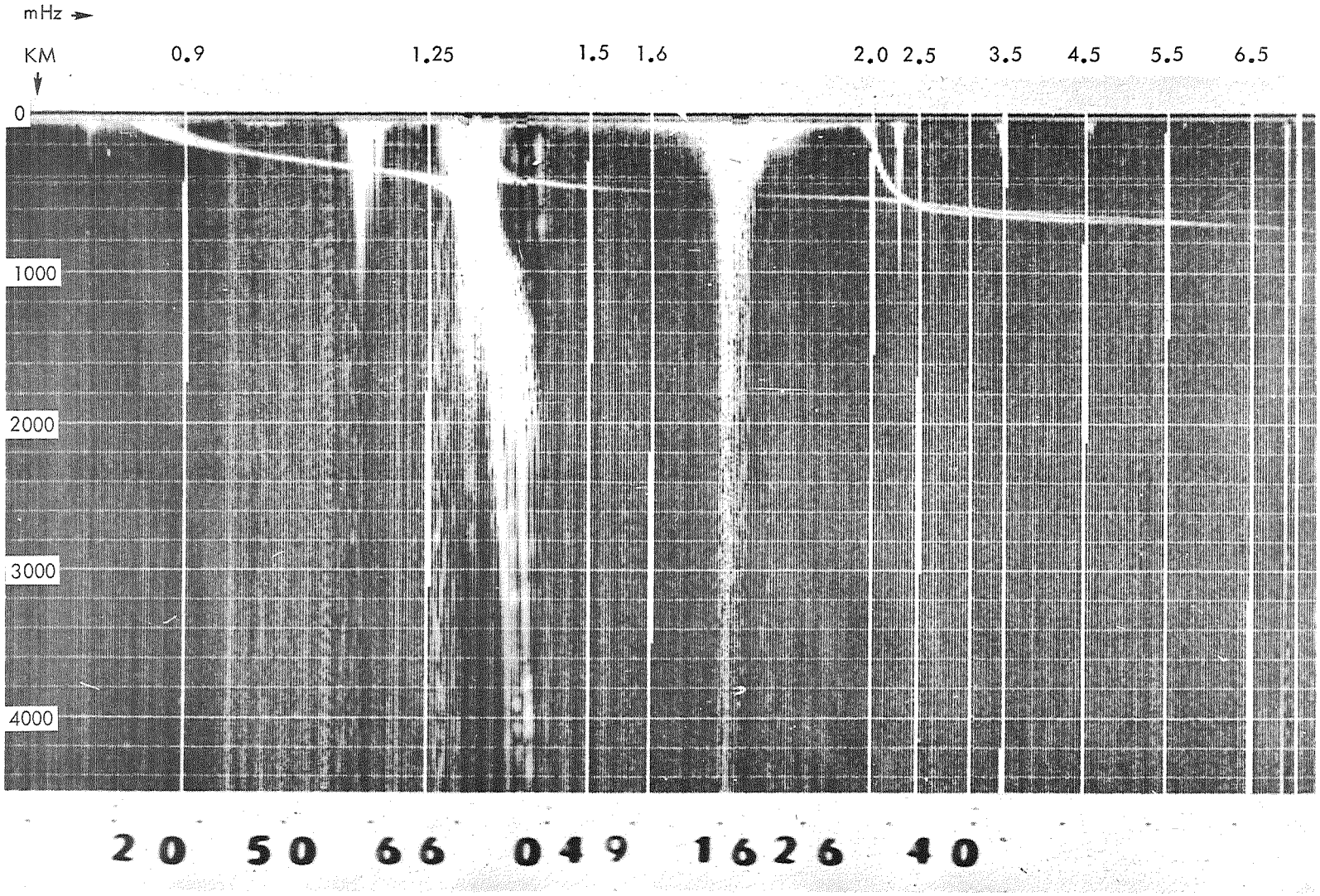

FIGURE 2–10 ALOUETTE II FILM IONOGRAM '#1626 40' (OTTAWA 966)

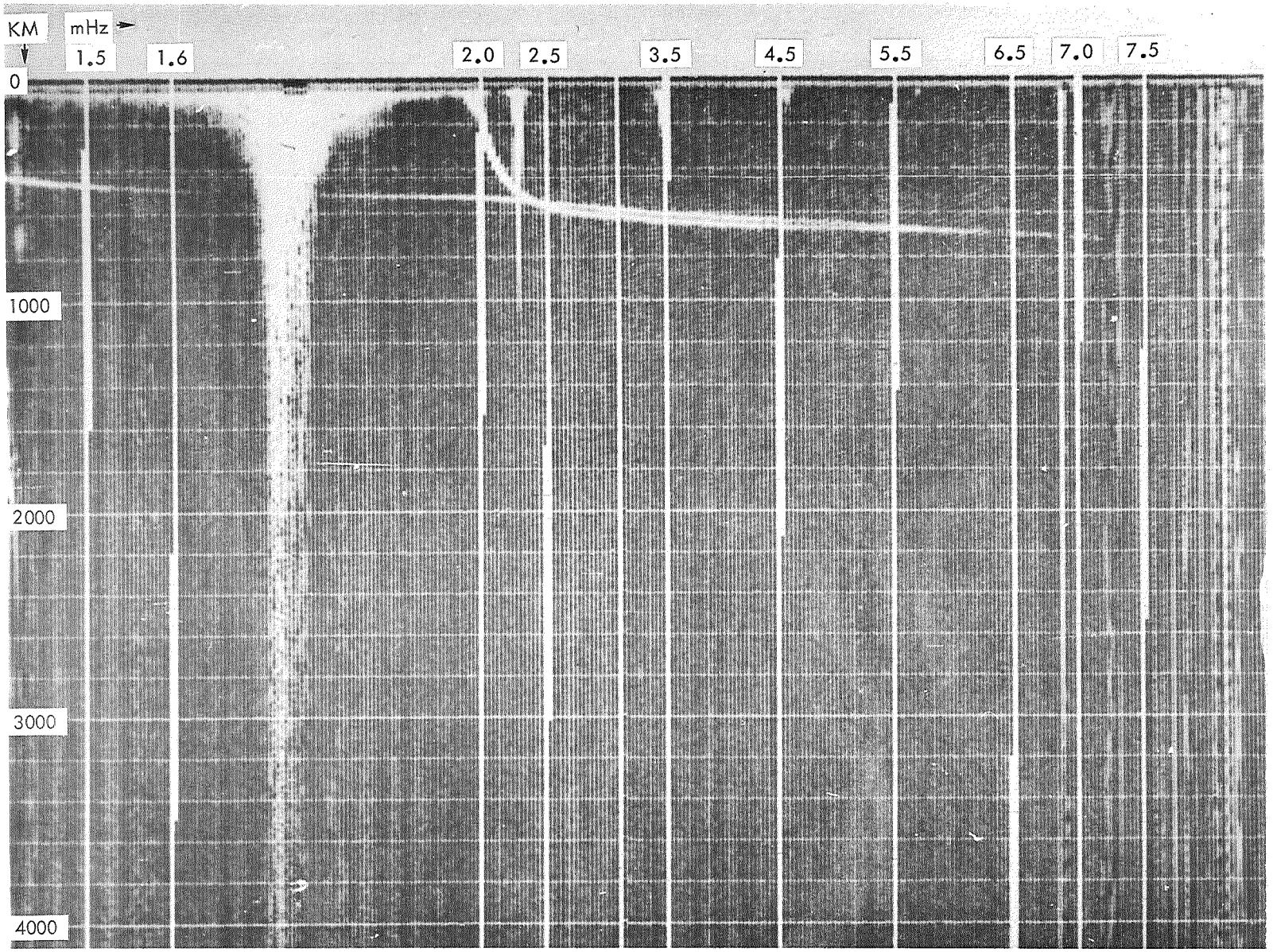

FIGURE 2–11 FILM IONOGRAM '#1626 40' EXPANDED RANGE AND FREQUENCY SCALES

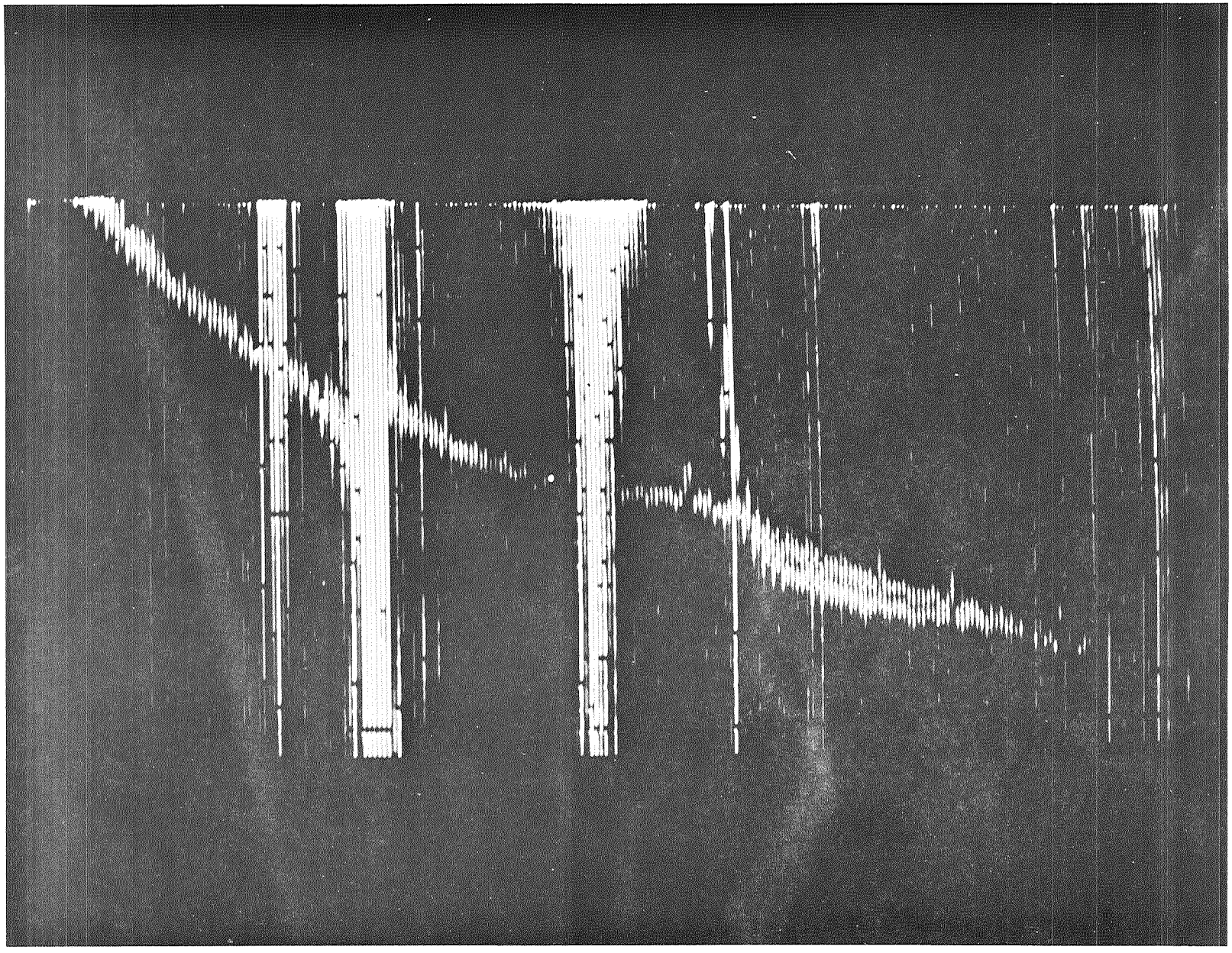

FIGURE 2–12 CRT IONOGRAM '#1626 40' EXPANDED RANGE SCALE

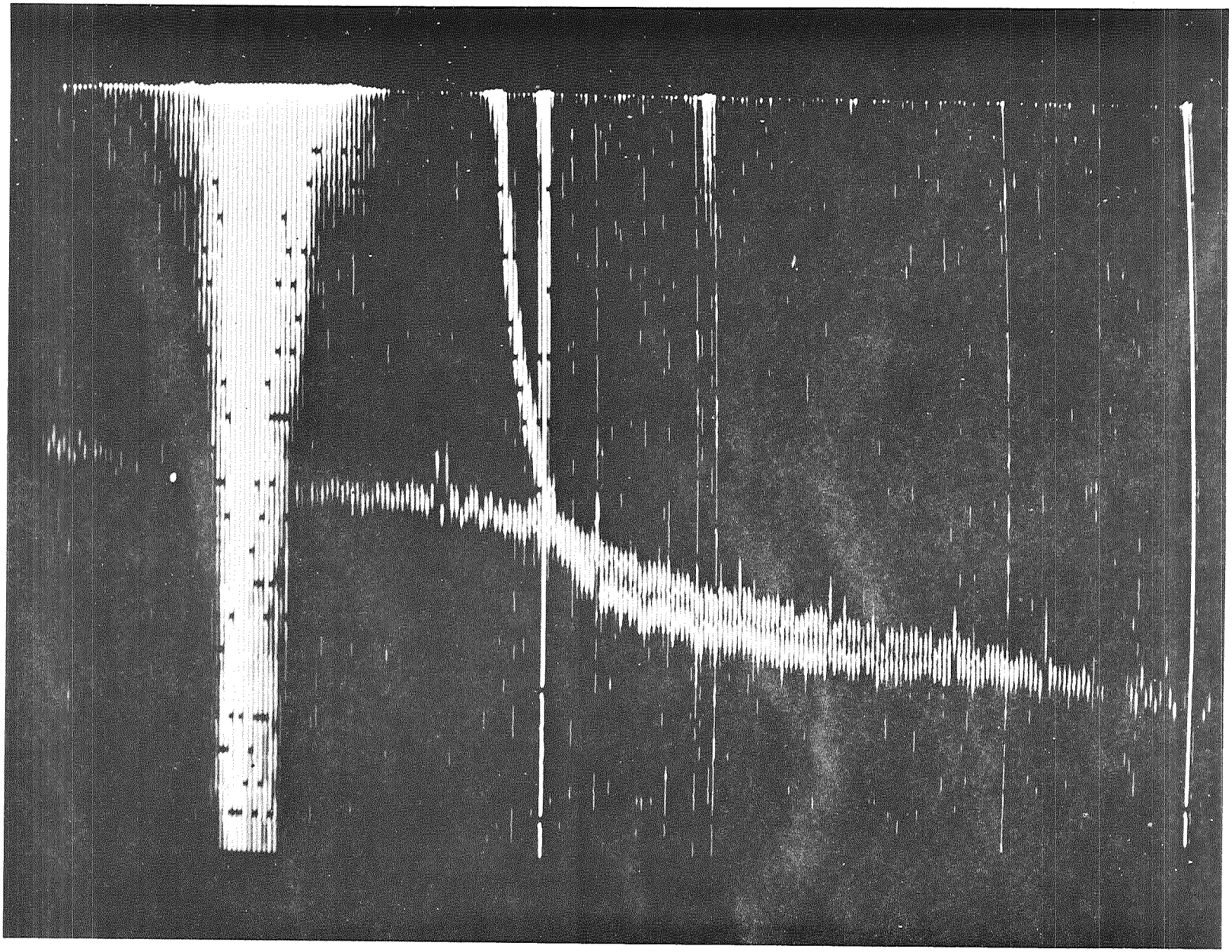

FIGURE 2–13 CRT IONOGRAM '#1626 40' EXPANDED FREQUENCY AND RANGE SCALE

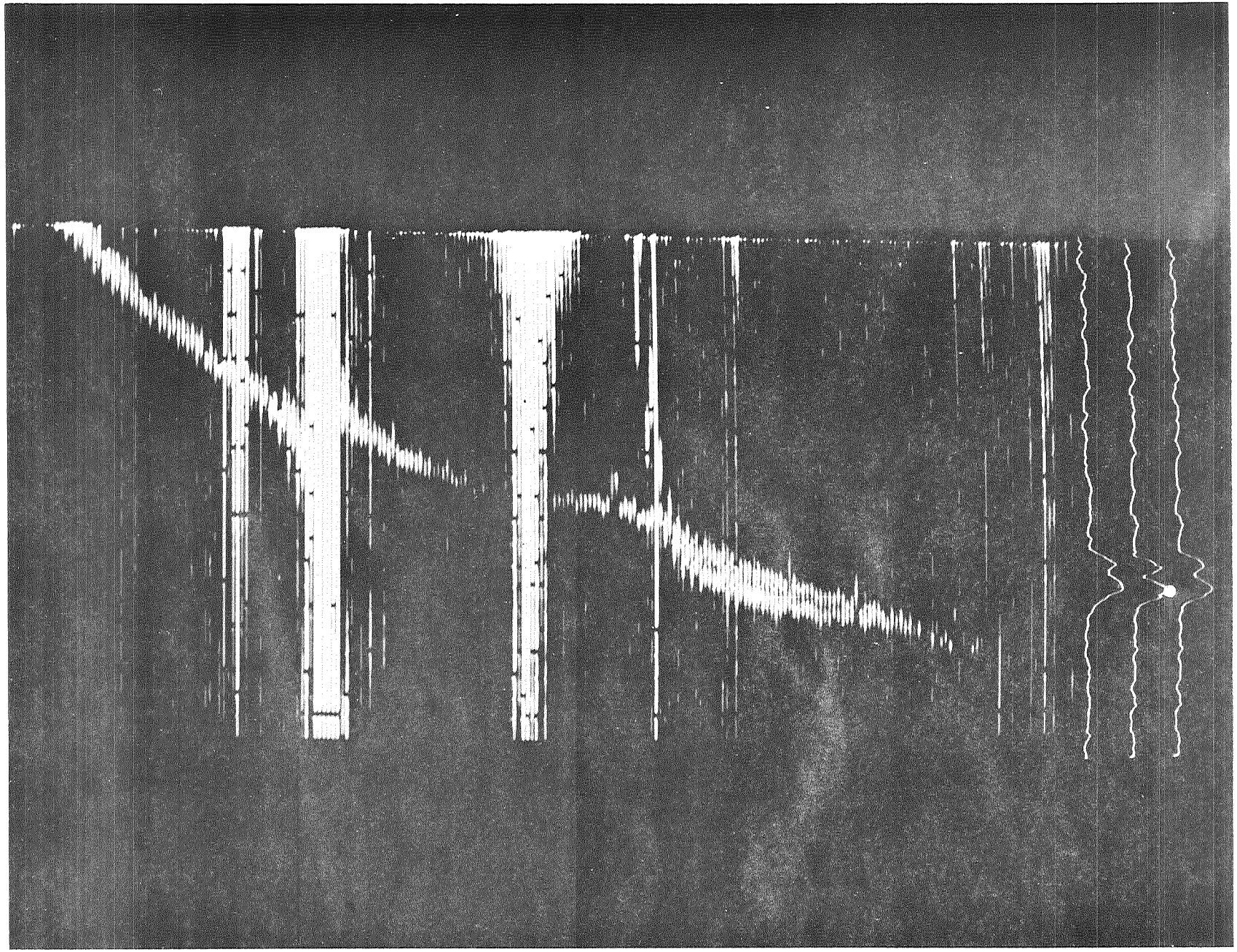

FIGURE 2–14 IONOGRAM '#1626 40' EXPANDED CRT DISPLAY WITH AUGMENTED A–SCAN AND CURSOR SPOT

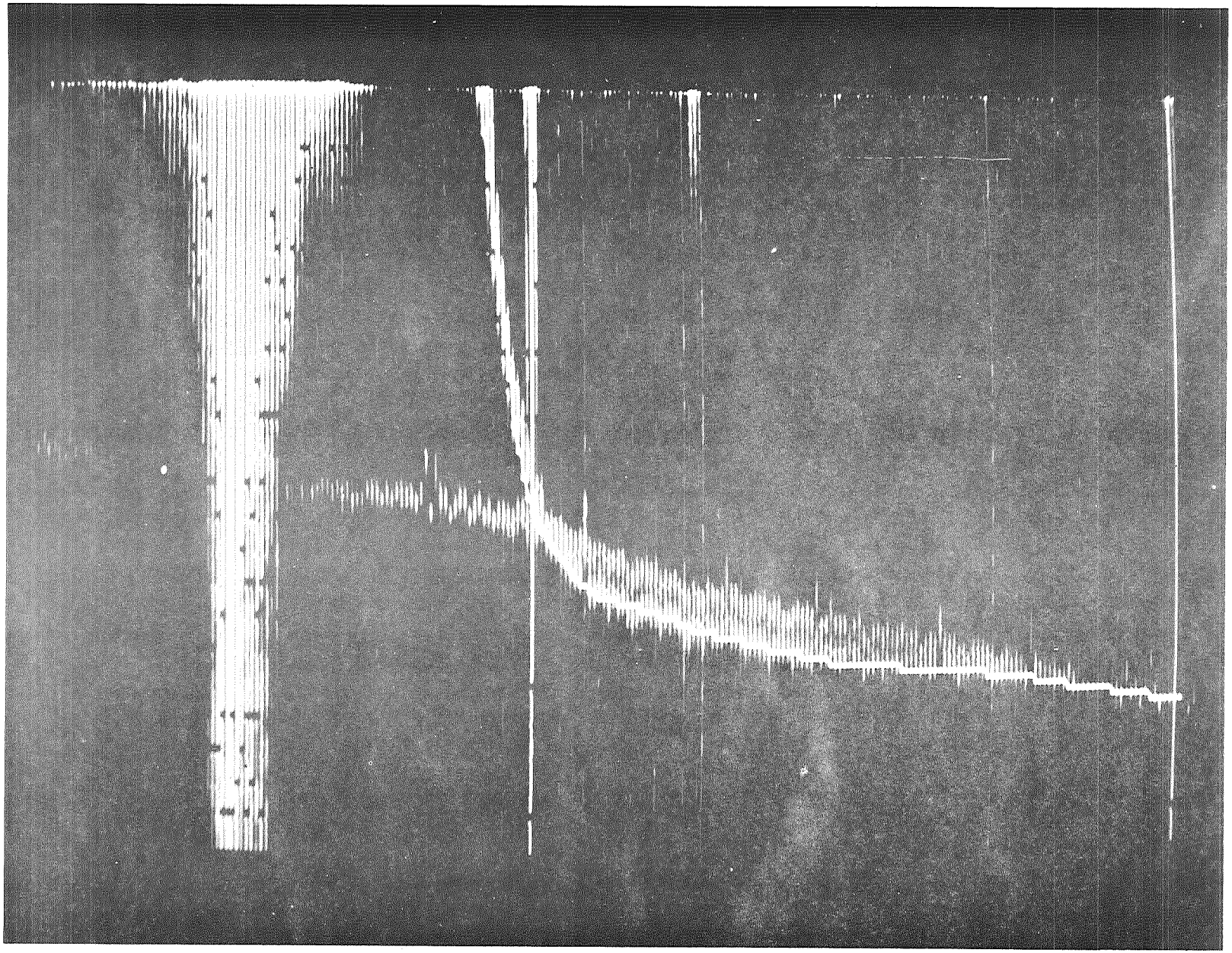

FIGURE 2–15 EXPANDED CRT DISPLAY WITH SUPERIMPOSED TRACK DISPLAY ON X–TRACE

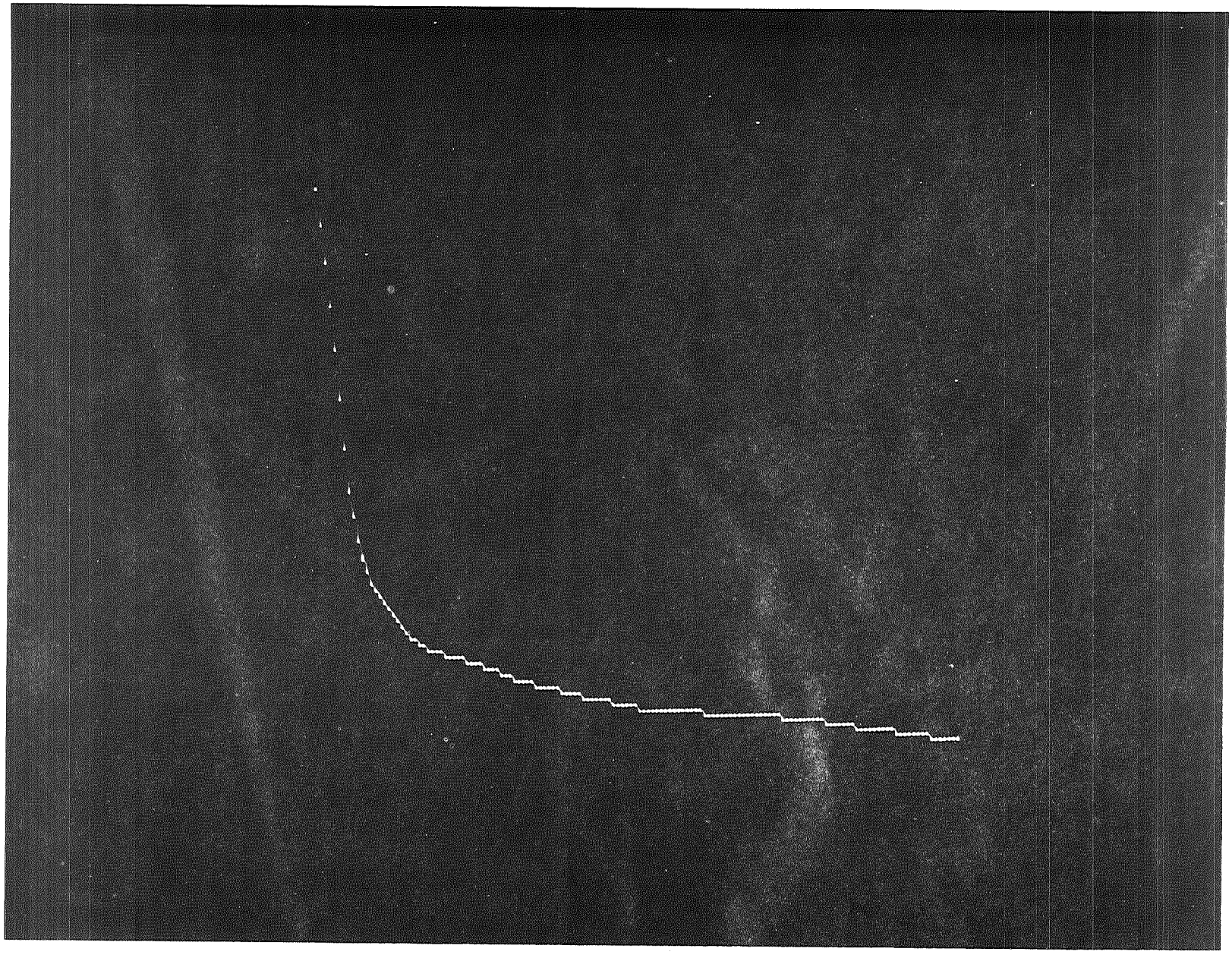

FIGURE 2–16 TRACK DISPLAY REPRESENTING X–TRACE

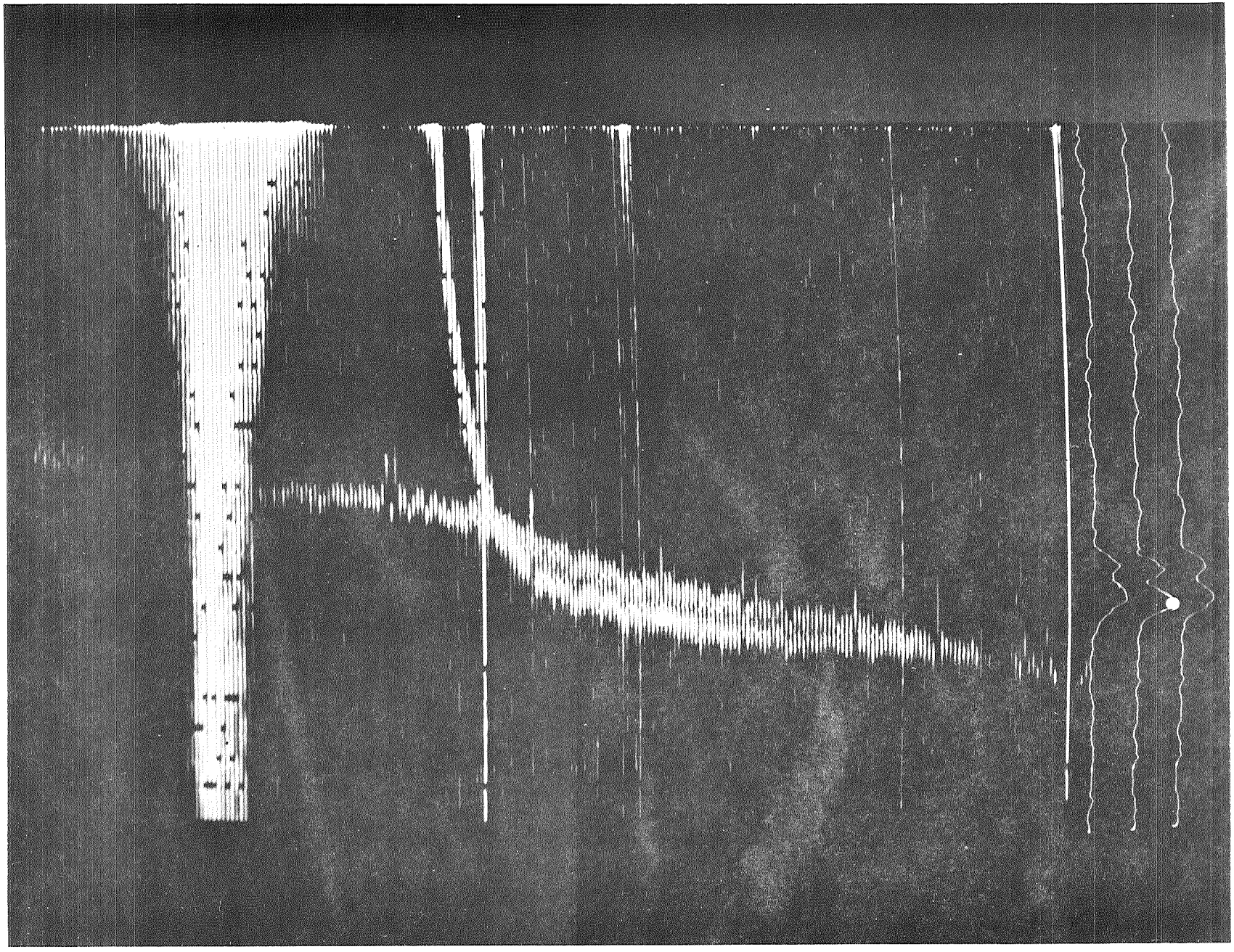

FIGURE 2–17 CRT IONOGRAM '#1626 40' WITH EXPANDED RANGE SCALE AND AUGMENTED A–SCAN DISPLAY WITH CURSOR SPOT

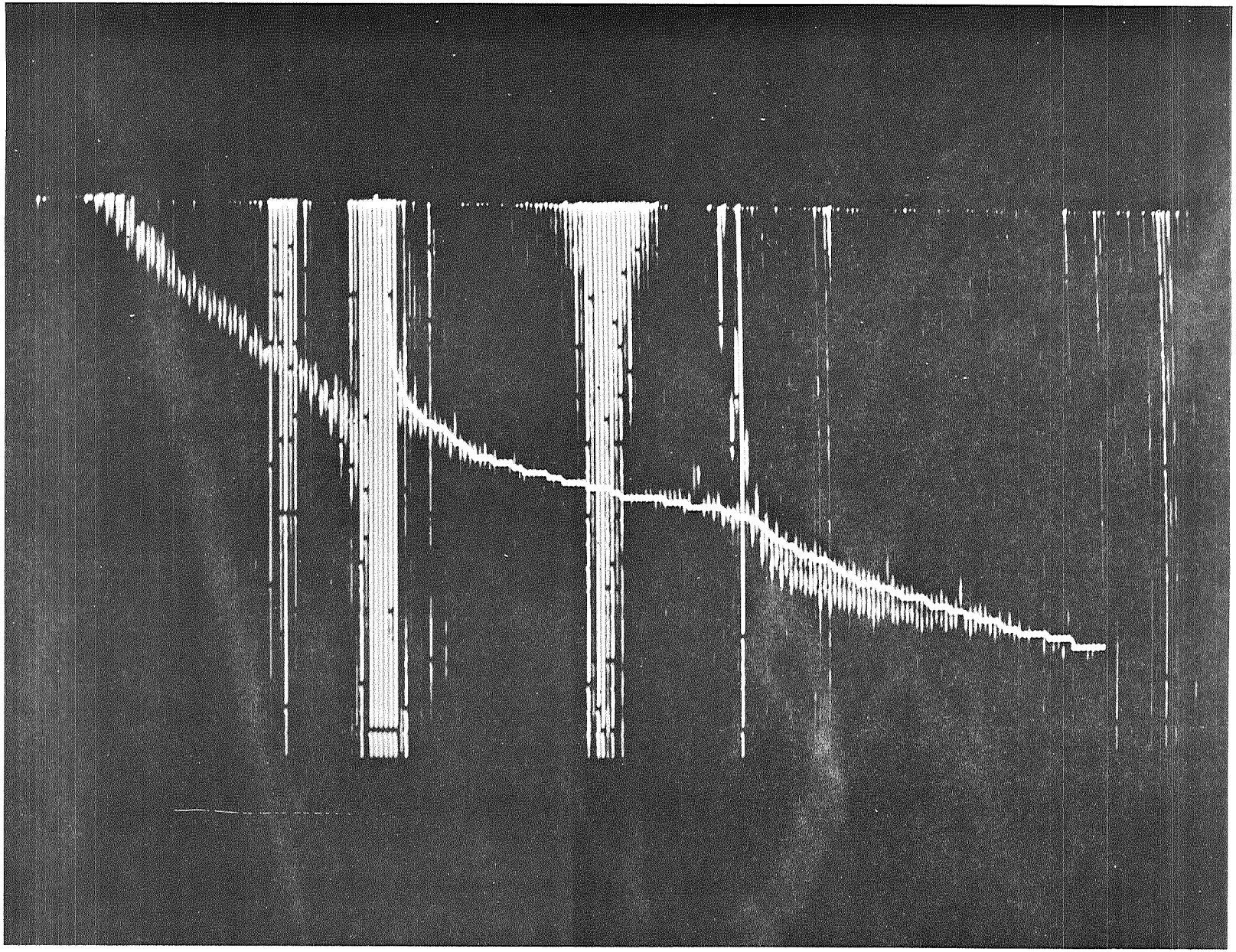

FIGURE 2–18 CRT IONOGRAM '#1626 40' WITH SUPERIMPOSED TRACK DISPLAY ON O–TRACE

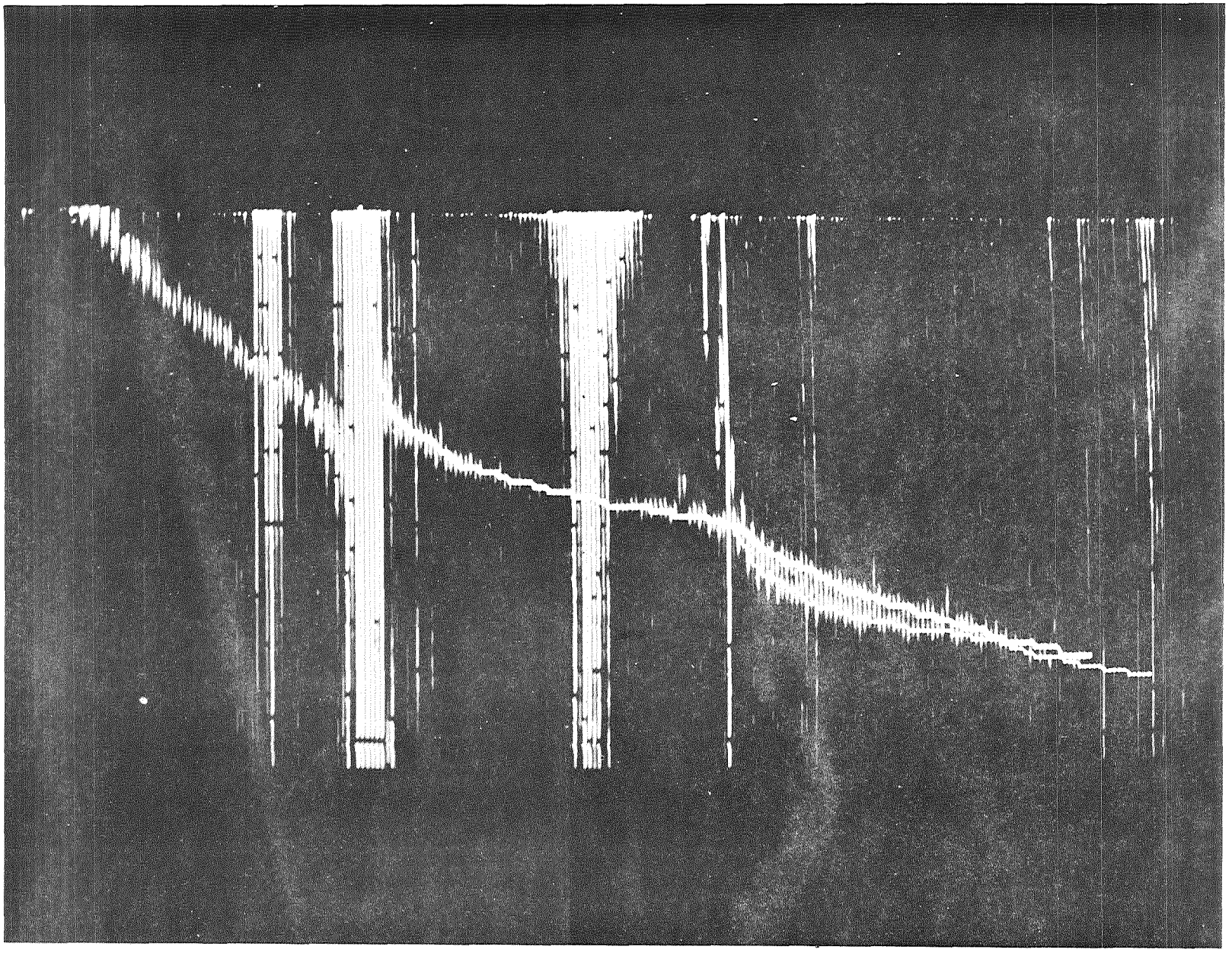

FIGURE 2–19 CRT IONOGRAM '#1626 40' WITH SUPERIMPOSED TRACK DISPLAYS ON X–TRACE AND O–TRACE

SECTION III

TOPSIDE SOUNDER DATA PROCESSING PROCEDURES

3.0 OPEN-ENDED PROCESSING

Data processing procedures that are now in use for processing topside ionospheric sounder data can be described as those of an open-ended system. The telemetry data goes through four basic processing phases during conversion to output data, as shown in the flow diagram in figure 3-1. In each of these processing phases, the data is converted to different forms, i.e., analog magnetic tape, film, punched cards, (or digital tape) and finally output data (tables and plots).

These four processing steps are more graphically illustrated by the drawings in figures 3-2 through 3-5. The steps in this processing procedure are separated in both space and time, and there is no built-in feedback in the system. This open-ended procedure has worked satisfactorily for processing the low-altitude (1000 km) thin-line ionograms from Alouette I, but as pointed out in section I, some high-altitude ionograms from Alouette II frequently do not provide sufficient information for an unambiguous scaling. As a consequence, it has become difficult if not impossible to process many high-altitude ionograms by following current procedures using equipment that is presently available.

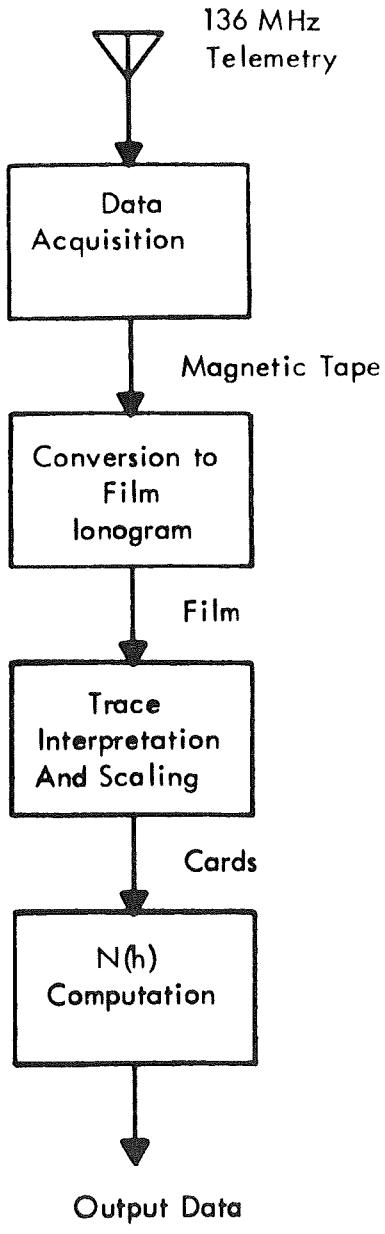

FIGURE 3-1. PRESENT TOPSIDE SOUNDER DATA PROCESSING STEPS

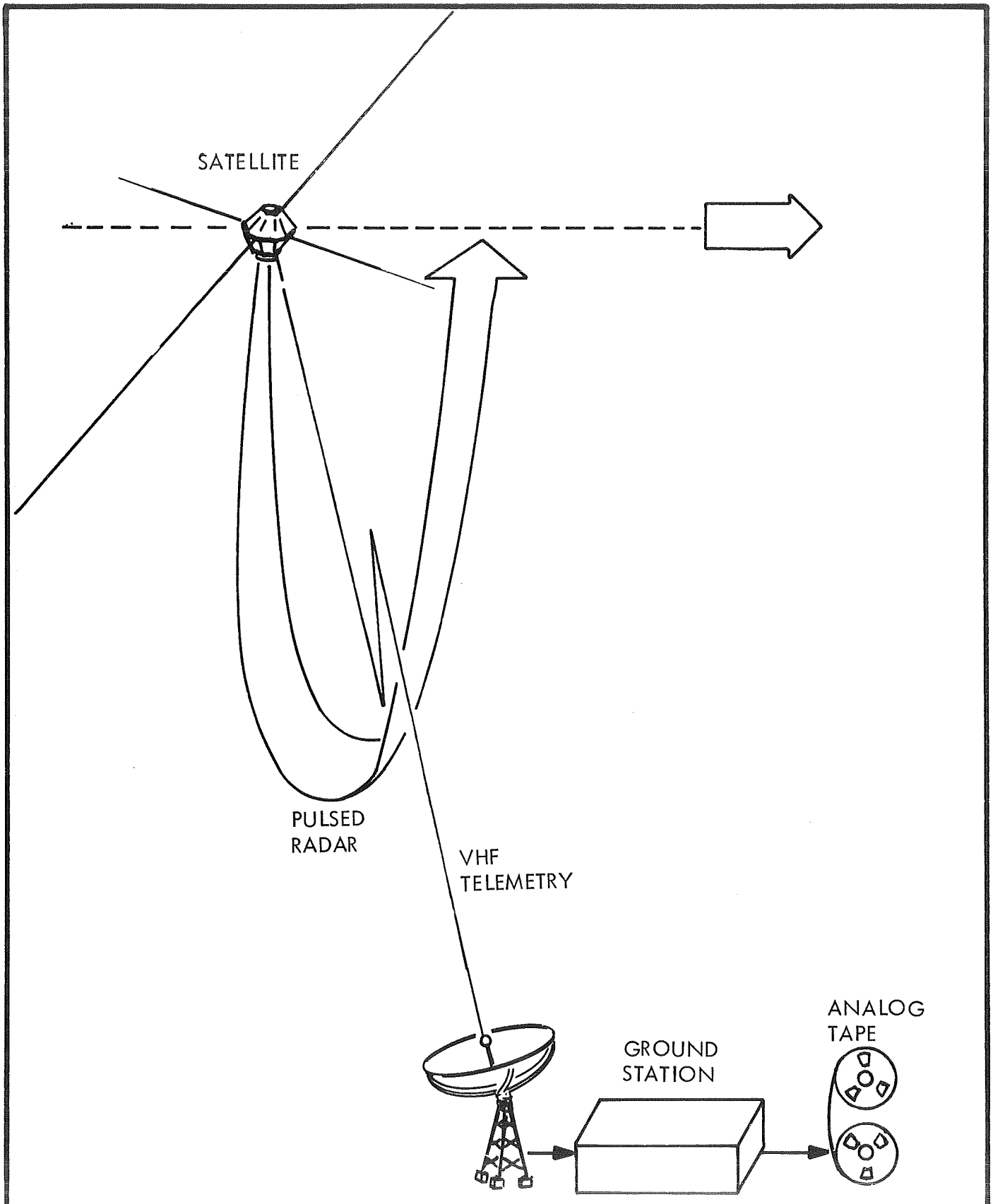

FIGURE 3–2 STEP 1 RECORDING OF VIDEO DATA ON MAGNETIC TAPE

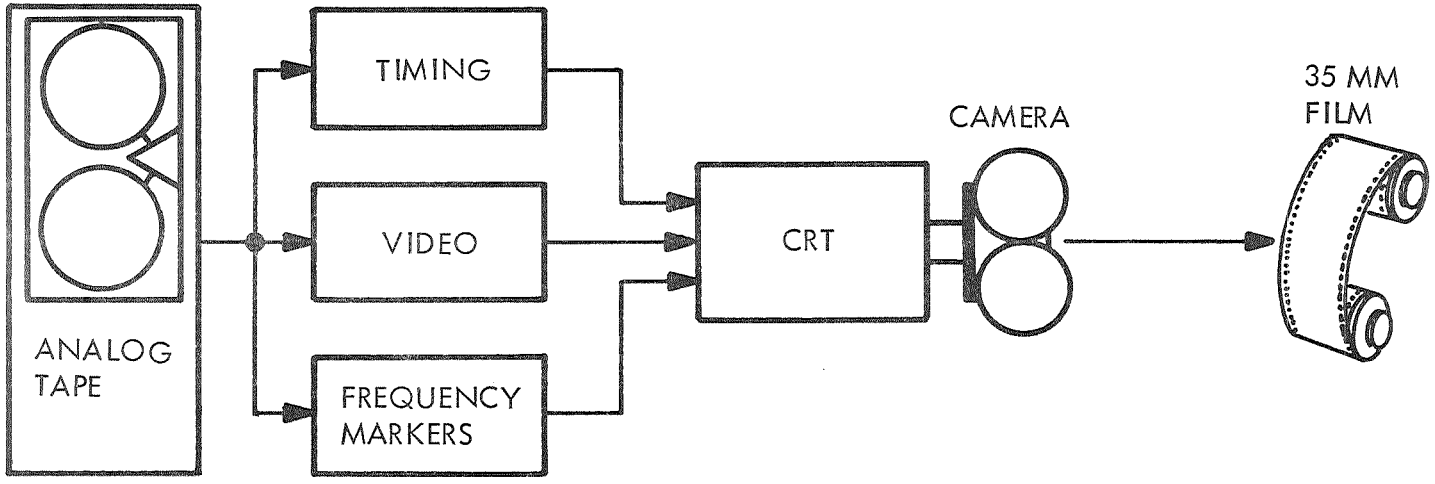

FIGURE 3–3 STEP 2 CONVERTING DATA ON MAGNETIC TAPE TO FILMED IONOGRAMS

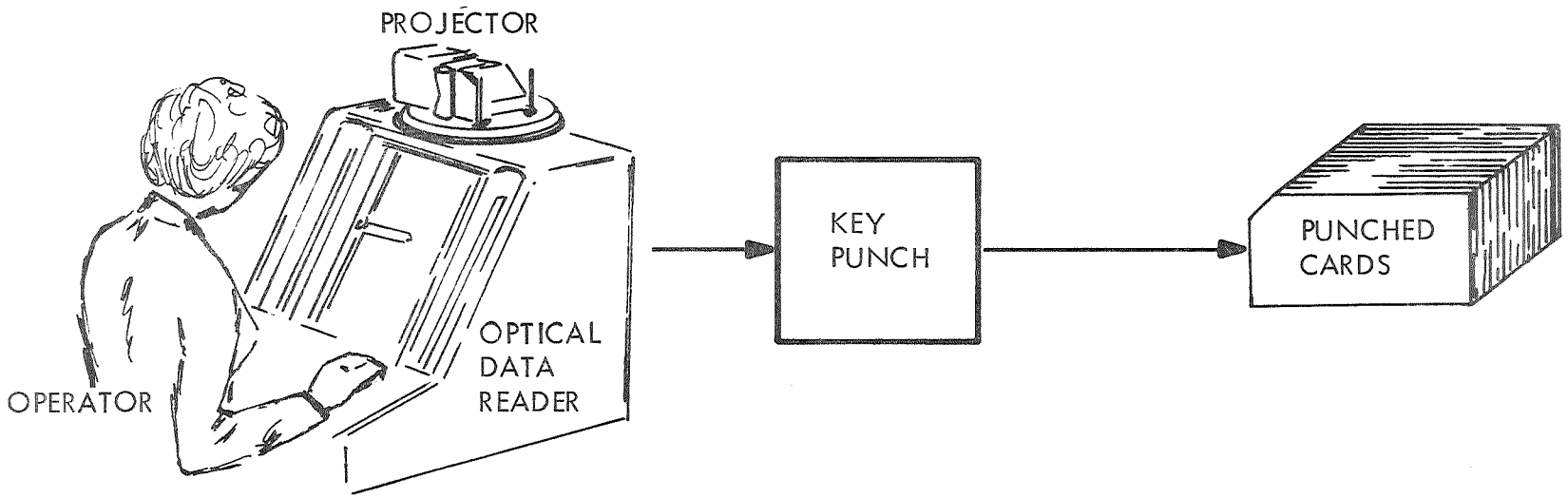

FIGURE 3–4 STEP 3 SCALING OF IONOGRAM FILMS

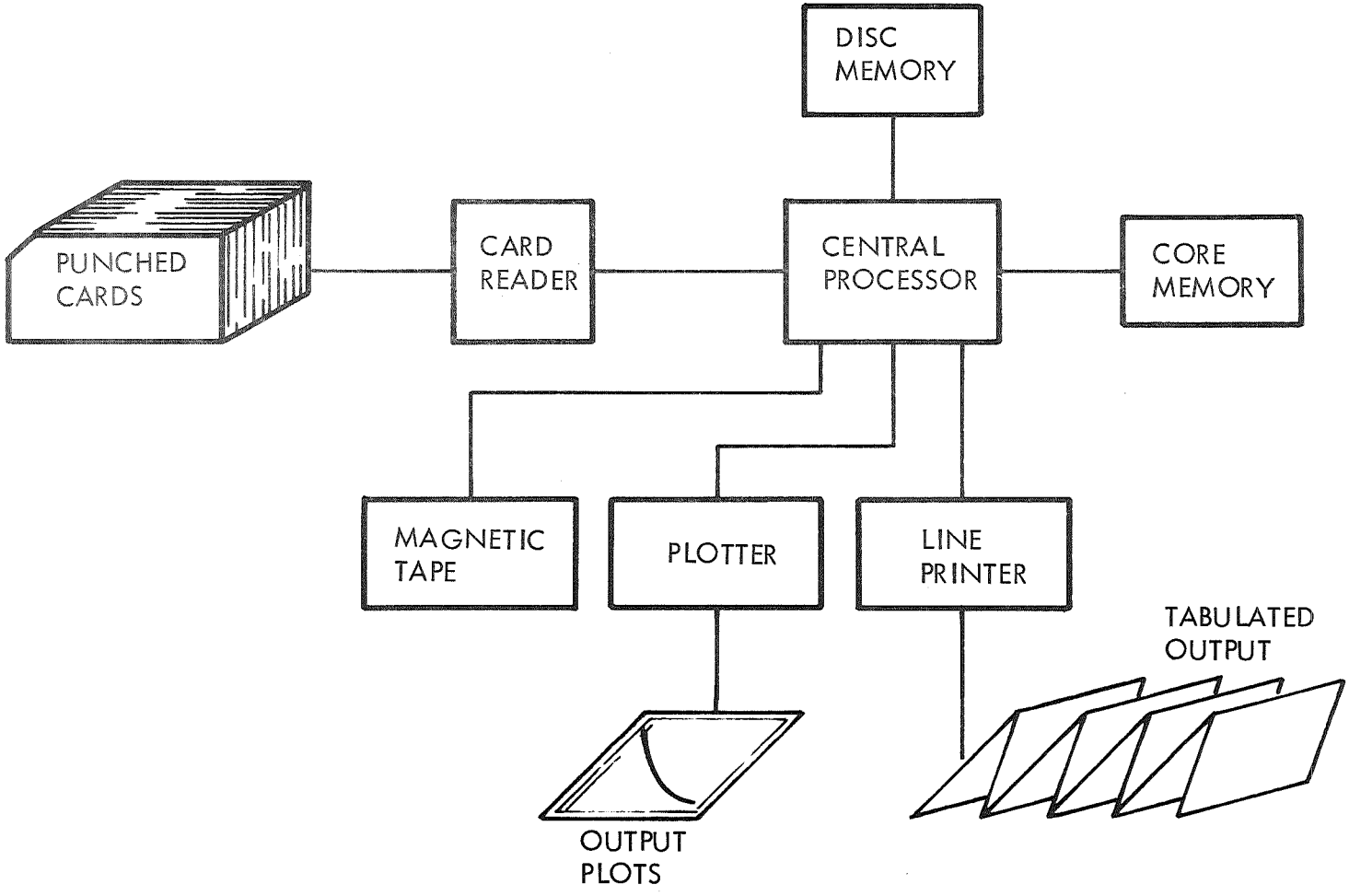

FIGURE 3–5 STEP 4 N(h) COMPUTATIONS

3.1 PROCESSING IONOGRAMS WITH SEMI-AUTOMATIC EQUIPMENT

This study was undertaken to investigate the overall data processing task in order to be able to recommend new equipment and procedures that would greatly speed up the processing cycle for simple ionograms, and at the same time provide means for coping with more complex high-altitude ionograms that are becoming a larger percentage of the backlog of data to be processed.

The recommended solution that has emerged from the study is based on the ideas and suggestions from scientists at NASA/ARC and the Canadian D.R.T.E., and from the Study Project Team.

The simulated man/machine communication link experiments have shown that the filmed ionogram phase can be duplicated electronically in real time.[1] A digitized version of the ionogram can be displayed on the CRT with a degree of flexibility not possible with a film ionogram. The operator can interpret and scale traces on a CRT display as easily as she can a projected film image.

With the direct input of $h_x'(f)$ data points to the computer, the punched card phase in current processing procedures is unnecessary.

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[1] All data is derived from analog tape playback and technically is not "real time". In this context "real time" refers to an ionogram image visible at the time the analog magnetic recording is reproduced.

3.2 CLOSED-LOOP PROCESSING

A major improvement in Topside Sounder data processing can be implemented by closing the loop on the processing chain so that the operator can see the results of her scaling, and make necessary changes or corrections until a computed N(h) profile matches the ionogram. In this manner the N(h) profile is arrived at by successive approximation, but the final data is likely to be a much more accurate representation of the ionosphere at the time it was probed than if the N(h) profile were computed from only one scaling on an open-ended basis.

A flow diagram of closed-loop ionogram processing with a semi-automatic data processor is shown in figure 3-6. In this method, video data from analog magnetic tape is digitized and input to the computer and the resulting ionogram is displayed to the operator on the CRT. As she scales the X-wave trace, the $h_x'(f)$ data points appear superimposed on the ionogram so that she continually evaluates her actions. When she is satisfied with the data point selections, she initiates $N_x(h)$ computation by depressing a button on the control keyboard. This is followed by computation of $\overline{h_o'(f)}$ data points using the inverse program and the resulting data points are displayed on the CRT superimposed on the ionogram. The operator then compares the $\overline{h_o'(f)}$ data points with the actual O-wave trace and evaluates the results of her initial scaling.

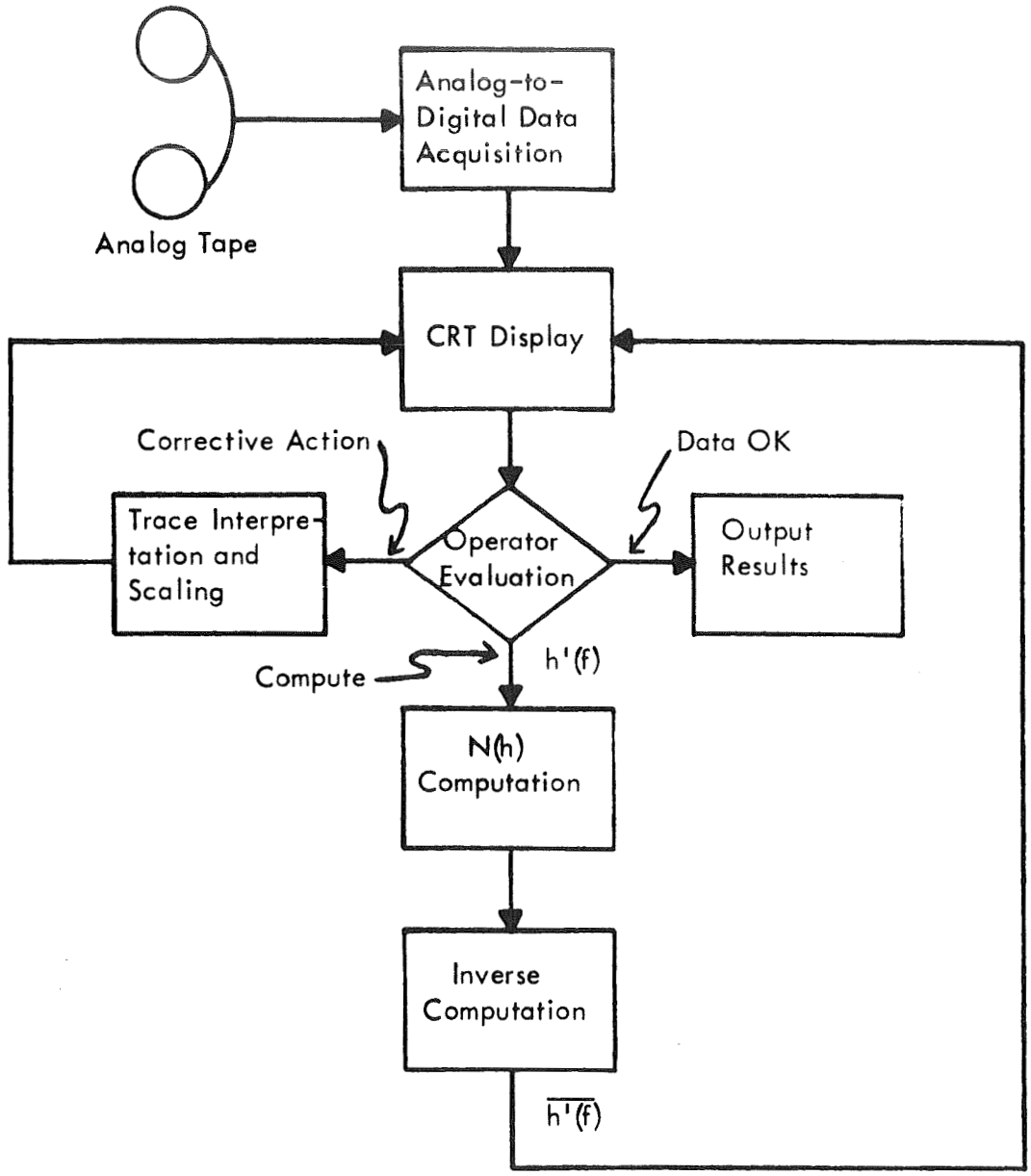

FIGURE 3-6. CLOSED LOOP IONOGRAM PROCESSING

When these $\overline{h_o'(f)}$ data points, that are computed from the scaling of the X-trace, satisfactorily match the observed O-wave trace, the operator may then approve the data point selection (via a keyboard entry) thus releasing the system to complete computation of the final output data with a high degree of confidence.

The time required for the forward[1] and inverse[2] computations with the present computer programs is only a matter of seconds, so that the elapsed time from the completion of manual scaling to the evaluation of the results is acceptable from a psychological feedback standpoint. The operator gets immediate reinforcement, whether positive or negative, and, if necessary, she can immediately initiate corrective action.

3.3 MANUALLY-CONTROLLED PROCESSING

A step-by-step procedure for a manually controlled closed-loop operation is as follows:

1. Mount the analog magnetic tape on the tape machine.

2. Select the start time of the desired ionogram in a pass.

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[1] N(h) Program for the Reduction of Alouette II Topside Ionograms to Electron Density Profiles -- Jack G.K. Lee, NASA/ARC --

[2] Reduction of Electron Density Profiles to Alouette II Topside Ionograms -- Jack G. K. Lee, NASA/ARC --

3. Start the tape machine and load the resulting digital A-scan data from an ionogram into disc memory.

4. Select the range and frequency boundaries for the ionogram and display the ionogram on the CRT.

   Comment: After her first view of the complete ionogram, the operator can change the frequency and range boundaries and display an enlarged view of that portion of the ionogram that is of interest.

5. Assign an index number indicating the relative quality of the ionogram; 1 is perfect, 9 is useless.

6. Place the cursor spot at the zero range of the exit frequency (f_{xs}) of the X-wave and enter this data point into the computer. Place the cursor spot at the frequency for maximum range of each of the observed resonance spikes and enter these data points into the computer.

   Comment: The computer knows the frequency and time of every line in the ionogram and also the range (virtual depth) of every picture element on each line of the display.

7. Move the cursor spot to select the remaining $h_x'(f)$ data points and enter these into the computer.

Comment: Data point selection is greatly aided by the augmented display of three A-scan lines to the right of the ionogram picture.[1] The middle A-scan line shows the amplitude profile of the line on which the cursor spot is positioned, while the other two lines show the amplitude profiles of the preceding and following lines. A pointer spot at the same range as the cursor spot moves up and down the middle A-scan line as the range of the cursor spot is varied. This enables the operator to select the peak, leading edge, or trailing edge of an echo pulse, as required.

8. Compute $h_x'(f) \longrightarrow N_x(h)$.

9. Compute $N_x(h) \longrightarrow \overline{h_o'(f)}$ and display on the CRT.

10. Evaluate results on the display and repeat 7, 8, and 9 until satisfied.

11. Assign an index number representing the quality of agreement between the scaled and computed data points for the X-, O-, Z-wave traces; 1 is perfect, 9 is unacceptable.

---

[1] See figure 2-5 preceding page II-17.

12. Compute final output data and produce printouts and plots.

3.4 MIXED-MODE OPERATION

Mixed-mode operation is a term that has been devised to describe a composite method of operation in which appropriately selected data points from both the O-wave and X-wave traces are used in the computation of the N(h) profile. Mixed-mode operation is a subset of closed-loop operation and so only those procedures that are unique to mixed-mode processing are described in this subsection.

In complex, high-altitude ionograms, the vertical reflection trace is frequently obscured by field-aligned traces that are often present for part of the record. The O-wave is also present for part of the record, but it is frequently discontinuous and also the origin of the O-wave is obscured by a resonance. The electron density computed from the initial few $h_x'(f)$ data points will provide the corresponding laminations of N(h) which can be used to compute $\overline{h_o'(f)}$ data points for display on the CRT. If these data points connect or align with the O-trace on the ionogram, it should then be possible to use scaled $h_o'(f)$ data points to compute additional laminations in N(h). In symbolic form, mixed-mode operation may be represented as follows:

$$h_x'(f) \longrightarrow N_x(h) \longrightarrow \overline{h_o'(f)}$$

$$h_o'(f) \longrightarrow N_o(h) \longrightarrow \overline{h_x'(f)}$$

This method of piecewise computation of laminations in the N(h) profile should make it possible to complete the N(h) profile for the ionogram or at least complete a major portion of it. At any time in the process the partial set of $\overline{h_x'(f)}$ and $\overline{h_o'(f)}$ data points can be displayed for comparison with scaled $h_x'(f)$ and $h_o'(f)$ data points. For the same lamination in N(h), the frequencies of the corresponding $h_o'(f)$ and $h_x'(f)$ data points will be different. Inverse computed data points will be added to both the O and X track display on each iteration. As the scaling procedure continues, this composite display of all data points will aid the operator in choosing the frequencies at which subsequent data points should be selected. When completed, the $\overline{h_x'(f)}$ data points can be evaluated with respect to the ionogram, and if any discontinuities are evident, the operator can make manual corrections. The operator now has the corrected set of $h_x'(f)$ data points from which the final N(h) profile can be computed.

3.5 SEMI-AUTOMATIC PROCESSING

Semi-automatic processing is a procedure by which more of the detailed scaling functions are relegated to the computer. Some of the functions which the computer can perform are described in the following paragraphs.

Scaling

The operator can interpret the X-wave by starting with the cursor spot at f_{xs} and in one continuous movement of arm and hand, outline the X-wave trace. Range

values for each line of the ionogram will be transferred to Track Store. Selection rules for $h_x'(f)$ data points will enable the computer to determine the frequencies at which h' is to be determined. The variety of scaling selection rules that have been considered are discussed in the following subsection.

The computer knows the frequency of every line in the ionogram and so it can select from Track Store the particular data points that satisfy the scaling selection rule. These data points then become the reference for correlation of data points from Pulse Store that now give the desired values of h' based on a maximum pulse amplitude criterion. After the operator has interpreted the X-trace, the time required for the computer to select a set of $h_x'(f)$ data points is negligibly small. Consequently, as soon as she has completed the interpretation of the trace, a set of computer-selected $h_x'(f)$ data points are displayed on the CRT for her approval.

As an alternate procedure, after scaling f_{xs}, the computer could use the scaling selection rule to determine the frequencies (lines) at (from) which data points are desired for N(h) profile computation. Then when the operator interprets the X-trace, only those data points at frequencies belonging to the set $h_x'(f_i)$, $i = 1,2,3,\ldots,$ n will be transferred to Track Store and then displayed.

If there is no data point for a given frequency in Pulse Store when the computer asks for it, a number of alternatives are possible:

1. The computer may instead accept the manually input data point in Track Store.

2. The computer can check lines on either side of the one in question and, if pulses are found that belong to the same track, it can interpolate a value of h' for the desired frequency (line).

3. The computer can flag the $h_x'(f)$ data point(s) that is (are) not available from Pulse Store and let the operator select h'.

In a similar manner, the operator can interpret the O-wave trace and store the data points for that track in a separate Track Store. The computer can then correlate from Pulse Store, and where data is missing across a portion of the O-trace, the computer can curve-fit between data points on each side of the gap. The accepted interpretation of the O-trace then becomes a reference for comparison of $\overline{h_o'(f)}$ data.

Scaling Criteria

The criteria for scaling ionograms has been the subject of considerable attention during the course of the study. Some of the criteria that have been considered are as follows:

1. Data points at equally spaced increments of frequency.

2. Data points at progressively increasing increments of frequency.

3. Data points equally spaced along the X-wave trace.

4. Data point spacing proportional to the rate of change of slope of the trace. Data points would be closer together where the slope was changing and further apart where the slope was reasonably constant.

5. Data points selected to give laminations in N(h) that are equally spaced in true height.

6. Data points selected to make the density ratios between laminations approximately equal.

Referring to the above selection rules by number, the following comments can be made:

Rule 1 is not a practical one to use. If the frequency increments are small enough for the data points to adequately represent the beginning portion of the X-trace, it requires too many data points to represent the complete trace. On the other hand, if a fewer number of data points are selected that are equally spaced in frequency, then the beginning portion of the X-trace is not adequately defined.

Rule 2 provides a means for adequately defining the beginning portion of the X-trace and still not have an excessive number of data points for the complete trace. This selection rule is a good compromise for the overall requirement and is presently used in some open-ended processing procedures.

Rule 3 is not practical to use due to the non-linear nature of f(t). In Alouette II, for example, the frequency sweep rate changes abruptly from 0.15 mHz/s to 1.0 MHz/s as the sounder frequency passes 2.0 MHz.

Data points selected according to Rule 4 would probably give a reasonably good distribution of laminations in the N(h) profile, but it would be difficult to implement, and is therefore not too practical.

Some experimenters have indicated that data points selected according to Rule 5 would provide an ideal distribution of laminations in the N(h) profile. Selection of data points that meet this criteria is virtually impossible for the initial scaling, but with closed-loop operation, data points that meet this criteria can be closely approximated for N(h) computation on the second iteration. In this method, the initial set of $h_x'(f)$ data points are selected according to Rule 2. From the resulting N(h) profile, a set of values of FN(J),FH(J), and DIP(J) are interpolated at equally spaced increments of true height, H(J). These variables then become the input data to the inverse program for computation of a

set of $\overline{h_x'(f)}$ data points which are then displayed on the CRT for operator evaluation. If more than one iteration is required to process the ionogram in closed-loop operation, subsequent $h_x'(f)$ data points are selected at the same frequencies as the $\overline{h_x'(f)}$ set and these will give laminations that are very nearly equally spaced in true height.

Comment: The magnetic field parameters need only be calculated in detail on the first iteration. On subsequent iterations, values of Y_i[1] can be obtained by inverse cube interpolation between laminations.

With the density ratio in a lamination defined as $\frac{N(h_{i+1})}{N(h_i)}$, the criteria of Rule 6 is equivalent to selecting data points that will give laminations in the N(h) profile that are equally spaced in log N. While the computer can easily do this for one ionogram on a closed-loop basis, the same values of H(J,K) used for other ionograms in the same pass, as described in the following subsection, may not meet the equally spaced in log N criteria. Selection according to Rule 6 is not considered practical at this time.

---

1 $Y_i = \frac{f_H}{f}$

Extrapolating Ionogram Data

Present methods of scaling ionograms and computing electron density profiles consider each ionogram as an isolated problem. The scaling operator may make visual comparisons from one ionogram to the next in a given pass, but comparative information of this type is not available to the computer.

Topside soundings from Alouette II produce ionograms that are spaced in time approximately 31.5 seconds and in distance approximately 220 kilometers. The orbital path length is approximately 51,000 kilometers, consequently the distance from one ionogram to the next is less than 0.5 percent of the path length of one orbit of the satellite. It is probably a reasonable assumption, then, that differences in intensity of the geomagnetic field, dip angle, and electron density from one ionogram to the next, at the same equally spaced increments of true height, can be linearily extrapolated to give a reasonably good approximation to the values of these parameters that will be observed for the next ionogram.

With the Inverse Program, the computer can use the predicted values of plasma frequency, gyro frequency, and dip angle, at specified equally spaced increments of true height, to compute a set of $\overline{h_x'(f)}$ data points for use as a reference to identify the X-trace in the next ionogram, i.e., as the correlation model to identify the pulses in Pulse Store that belong to the set called X-trace.

As mentioned previously, some experimenters have indicated that a preferred method of selecting $h_x'(f)$ data points along the X-Trace is to select them at frequencies that will result in laminations in the N(h) profile that are equally spaced in true height. Selection of data points that meet this criteria is virtually impossible, if an operator is scaling an ionogram as an isolated open-ended problem. However, by linear extrapolation of data from previous ionograms at equally spaced increments of true height, a good approximation to the set of $h_x'(f)$ data points that meet this criteria can be computed by the Inverse Program.

The satellite orbital program will be resident in memory, or else the necessary data from a refined world map listing will be available so that true height of the satellite, h_1 for the next ionogram can be used to evaluate coefficient a_2, equation (2) in the Inverse Program.

Extrapolating Procedure

Assuming for the moment that all of the ionograms in the pass are usable, a set of $h_x'(f)$ data points are scaled from an interpretation of the X-trace of Ionogram No. 1 according to scaling selection rule No. 2. Computation of the N(h) profile using open-ended, closed-loop, or mixed-mode techniques will give a laminated model of the ionosphere from which the plasma frequency, gyro frequency, and dip angle for equally spaced increments of true height can be interpolated from the parabolic in log (X) assumption. This procedure is repeated for Ionogram No. 2.

Designate the input variables for the Inverse Program for one ionogram as:

FN(J,1)
FH(J,1)
H(J,1)
DIP(J,1)

and for the next ionogram in the pass as:

FN(J,2)
FH(J,2)
H(J,2)
DIP(J,2)

where the H(J,K) are equally spaced[1] increments of true height and are the same for each ionogram. Compute the differences:

$$\Delta FN(J) = FN(J,2) - FN(J,1)$$
$$\Delta FH(J) = FH(J,2) - FH(J,1)$$
$$\Delta DIP(J) = DIP(J,2) - DIP(J,1)$$

Then as a first approximation, the values of these parameters in Ionogram No. 3 will be:

$$FN(J,3) = FN(J,2) + \Delta FN(J)$$
$$FH(J,3) = FH(J,2) + \Delta FH(J)$$
$$DIP(J,3) = DIP(J,2) + \Delta DIP(J)$$

which are the input variables required for the inverse program to compute a set of $\overline{h_x'(f)}$ data points.

---

[1] Note: It is not essential that the values of H(J,K) be spaced equally. The only requirement is that the set of H(J,K) be the same for all ionograms in a pass.

These $\overline{h_x'(f)}$ data points will give the frequencies at which the virtual depth of the new X-wave is to be determined from the interpretation of the X-trace.

In many cases a correlation of this set of $\overline{h_x'(f)}$ data with Pulse Store will give the necessary set of $h_x'(f)$ data points for N(h) computation, except for f_{xs} which is not usually in the Pulse Store. Any $h_x'(f)$ data points that are missing including f_{xs} can be input by the operator via the movable cursor spot.

The N(h) profile for Ionogram No. 3 is computed and then values for the input variables are interpolated for the inverse program at the same equally-spaced increments of true height as before. The Δ values derived as differences between ionograms 2 and 3, when added to the set of variables for Ionogram No. 3 become the predicted set of variables of Ionogram No. 4, etc.

Rather than extrapolate values for the gyro frequency and dip angle as described above, an alternative method would be to scale f_{xs} and determine the time of the next ionogram. From this the satellite orbital program will give the geographic location at which the magnetic parameters (B, θ) are to be computed. This procedure would not require significant additional computation because values of (B, θ) for the set H(J,K) are computed for each ionogram anyway. With this alternative method, only the set FN(J,K) would be extrapolated.

3.6 AUTOMATIC DATA PROCESSING

A fully automatic Topside Sounder data processing system is not yet envisioned, but it appears possible to approach automatic processing of good thin-line ionograms with an operator simply monitoring the processing operation and approving or disapproving the results from each ionogram.

The concept of automatic processing of Topside Sounder data is an extension of the method, outlined in the previous subsection, for predicting where the X-trace of an ionogram will be, based on extrapolating data from previous ionograms at equally spaced increments of true height. The predicted X-trace then becomes the correlation model for selection of pulses from Pulse Store that belong to the set called "X-trace." This concept of automatic processing also assumes that multiple iteration closed-loop processing is not required and that the operator will approve the results of the N(h) profile on the first iteration.

Whether f_{xs} can be determined automatically has not been investigated in this study. There will also be variations in the ends of X-wave traces where a cusp exists at the penetration frequency. The operator may choose to make a data point selection at the end of the trace.

3.7 GEOMAGNETIC FIELD COMPUTATION

Computation of the geomagnetic field as a subtask within the N(h) program takes a rather significant amount of time. This computation is based on a spherical harmonic expansion representation of the field with coefficients from Daniels and Cain. However, the detailed profile of the magnetic field need be computed only once for each ionogram. Values of B for subsequent computations in closed-loop operation can be derived by inverse cube interpolation between laminations of the first N(h) profile computation for each ionogram.

It may not even be necessary to compute the geomagnetic field, by means of the refined field model equations, at each of the lamination levels in the N(h) profile. A determination could be made of the minimum number of true height levels required for computing B, with the refined field model equations, that would allow intermediate values of B to be computed, with sufficient accuracy, by inverse cube interpolation.

For example, assume that laminations for the prediction model of the N(h) profile are to be spaced every 100 km of true height from 400 km to 3000 km. Compute the magnetic induction B at 500 km intervals of true height. This would require only six values of B that need be computed using the refined field model equations. Values of B at the intermediate levels of true height could be obtained simply by inverse cube interpolation using

the formula:

$$B = B_i \left[\frac{Re + h}{Re + h_i} \right]^{-3}, \quad i = 1,2,\ldots,6$$

where Re = Radius of earth

h = true height

In this example, the maximum range over which the inverse cube interpolation is used is only $\pm$250 km either side of the 500 km intervals of true height. Reducing the number of times the subroutines, for computation of the geomagnetic field, are called, will make a significant reduction in the running time of the N(h) program.

3.8 PROCESSING IONOGRAMS IN REVERSE SEQUENCE

It often happens that the first few ionograms in a pass of a satellite are not as good as the ones received when the satellite is nearer the ground receiving station. As soon as one or two ionograms have been processed, the computer knows the start time of all the other ionograms in the pass. With a tape search and control system operating with the timing code translator, it becomes practical to process data directly from magnetic tape in reverse sequence. The procedure for processing ionograms in reverse sequence is as follows:

a. Read ionogram forward.

b. Rewind two ionograms.

c. Read next ionogram forward, etc.

With reverse sequence processing, the better ionograms, say in the middle of a pass, can be processed first and then data can be extrapolated in both directions to assist in processing the ionograms at each end of the pass.

3.9 CONTOUR PLOTS

Final data presented in data books is usually shown plotted in the form of contour plots of electron density N at constant values of true height, h. It might be considered desirable to smooth the contour curves by some criteria, e.g., least squares error. Where there are significant differences between the smoothed contour curve and the original N(h) data points, the ionograms from which these data points were derived could be rechecked. It would be possible to compute $\overline{h_x'(f)}$ and $\overline{h_o'(f)}$ from the smoothed N(h) profile data from contour plots and compare these sets of data points with the X-wave and O-wave traces on the ionogram, and from this ascertain whether or not the smoothed data is acceptable.

SECTION IV

CENTRAL PROCESSOR

4.0 GENERAL

This portion of the study was conducted to determine the performance requirements for the Central Processor and compare these requirements with present day commercially available digital computers.

4.1 DATA FLOW

Prior to entering into a discussion of the detailed performance requirements of the Central Processor within a Semi-Automatic Topside Sounder Data Processor, it is convenient to review briefly the general flow of data through the recommended system.

The system will be capable of acquiring Topside Sounder data from analog magnetic tape recordings and/or filmed ionograms. In the case of the magnetic tape mode, all data is derived from playback of data recorded on analog magnetic tape. As indicated in the data processor block diagram figure 4-1, the video information is usually recorded as a wide-band FM signal with a nominal ± 40 percent deviation. Alouette II topside sounding recordings may involve a separate ± 7.5 percent deviation FM subcarrier to transmit frequency markers. Also recorded on the analog tape are a reference pilot tone and NASA 36-bit range time code, as well as unrelated signals from other satellite functions.

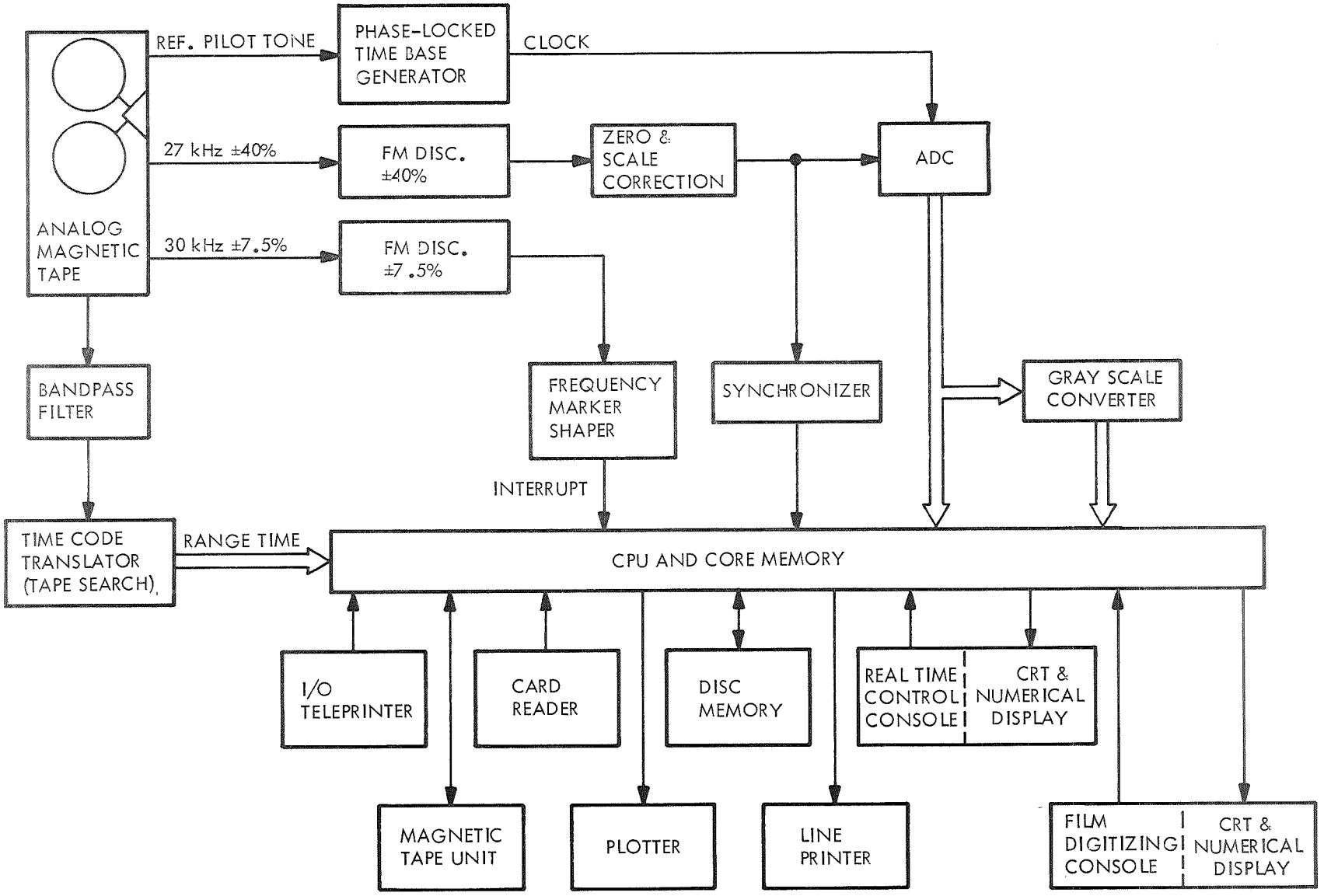


FIGURE 4–1 SEMI-AUTOMATIC TOPSIDE SOUNDER DATA PROCESSOR

4.1.1 DIGITIZED VIDEO

As indicated in the system block diagram, the demodulated video emerges from an FM discriminator and is directed through certain signal conditioning equipment to a high-speed analog-to-digital converter (ADC). This converter digitizes the Topside Sounder radar video at an equivalent real-time rate of 30,000 samples-per-second. The ADC produces 6-bit digital data samples at 5 km intervals. In some cases, the analog signal is a composite of video and frequency marker data. The resulting digital operands from the ADC are transferred to the Central Processor Unit (CPU) magnetic core memory. In normal operation this data would be assembled within the magnetic core memory into separate records corresponding to each video "line" and then transferred to disc memory.

The phase-locked time base generator, zero and scale correction servos, frame synchronizer, and line synchronizer, operate in conjunction with the analog-to-digital converter in order to maintain proper synchronization with the reproduced Topside Sounder telemetry signal. Descriptions of these and other peripheral devices will be found later in this report.

4.1.2 GRAY-SCALE DATA

The measurands output from the ADC are also presented to a gray-scale generator. This device examines each measurand and assigns a particular gray scale code that is proportional to the value (amplitude) of the sample.

The 2-bit gray-scale value for each sample is transferred to core memory, accompanying its associated digitized A-scan measurand and is ultimately transferred to disc memory along with the digitized A-scan video data.

4.1.3 RANGE TIME AND FREQUENCY MARKERS

Concurrent with the digitizing operations, the range time code is read from the analog magnetic tape by the time code translator. The translated universal time code is thus available to the Central Processor and is used to annotate the significant events within each ionogram, such as the appearance of the frame sync pulse, each line sync pulse, and in some cases, the appearances of each frequency marker. This schedule of events is noted and transferred to disc storage. Thus, the information representing a complete ionogram resides on the magnetic disc, complete with exact range time annotation and frequency marker information.

4.1.4 OVERLAP PROCESSING

While a second ionogram is undergoing the same translation process, from the analog magnetic tape to storage in digital form on the magnetic disc, the Central Processor may commence further processing of the first ionogram. In response to operator request, the gray-scale information corresponding to the first ionogram is converted to a compressed data format and is transferred to a bank of memory dedicated as display refresh storage for the CRT real-time ionogram. The operator then interprets the CRT display and selects traces of interest and follows the procedures described in Section III until she is confident that

proper traces have been scaled. In the course of this process, an electron density calculation is performed. The final results of these validated calculations are transferred to a section of disc memory where they may be collected until a complete report is assembled. At that time the data is formatted and listed on the peripheral line printer. In some cases, the data may also be prepared for output via the peripheral digital plotter.

While the operator is conversing with the processor via the CRT display and her control keyboard, the Central Processor continues to input digitized data representing the next ionogram. Consequently, when the first ionogram processing is complete, the system has the next ionogram ready for immediate display. The processing cycle is repeated thereafter.

In summary, the generalized data flow for data derived from magnetic tape originates from the analog magnetic tape unit, passes through the demodulation equipment and synchronization equipment to the analog-to-digital converter. The video data is then appended with gray-scale information and is transferred through the Central Processor magnetic core to disc memory. Later, upon operator request, the video data is returned from disc to magnetic core and is displayed on the CRT. Selected elements of the digitized video data then become the input variables for N(h) computations. The resulting N(h) profiles are stored temporarily, and are later printed and/or plotted.

4.2 PROGRAM EXECUTION RATE

For obvious economic reasons, it is not envisioned that a new special-purpose processor would be designed for this application. Instead, an existing commercial general-purpose digital computer would be incorporated as the system Central Processor.

In order to be justifiable economically, a semi-automatic system of this scale should be capable of processing at least 50 simple thin-line ionograms per hour. An example of a low-altitude, thin-line ionogram is shown in figure 4-2.

Similarly, the system should be capable of processing accurately at least 15 complex ionograms per hour. Here the term "complex" refers to ionograms with multiple echo traces (perhaps due to field-aligned echoes). Also, these complex traces may be incomplete, and in part obscured. Sample ionograms shown in figures 1-1 and 4-3 exhibit certain of these perturbing properties. (These examples are not intended to represent any particular limiting case, but rather are offered to indicate generally the distinction between simple and complex traces.)

Data accuracy is a key consideration. Processing speed is a subordinate goal in comparison with data accuracy and confidence. The primary objective is to maintain a high degree of confidence that proper echoes are selected and processed accurately.

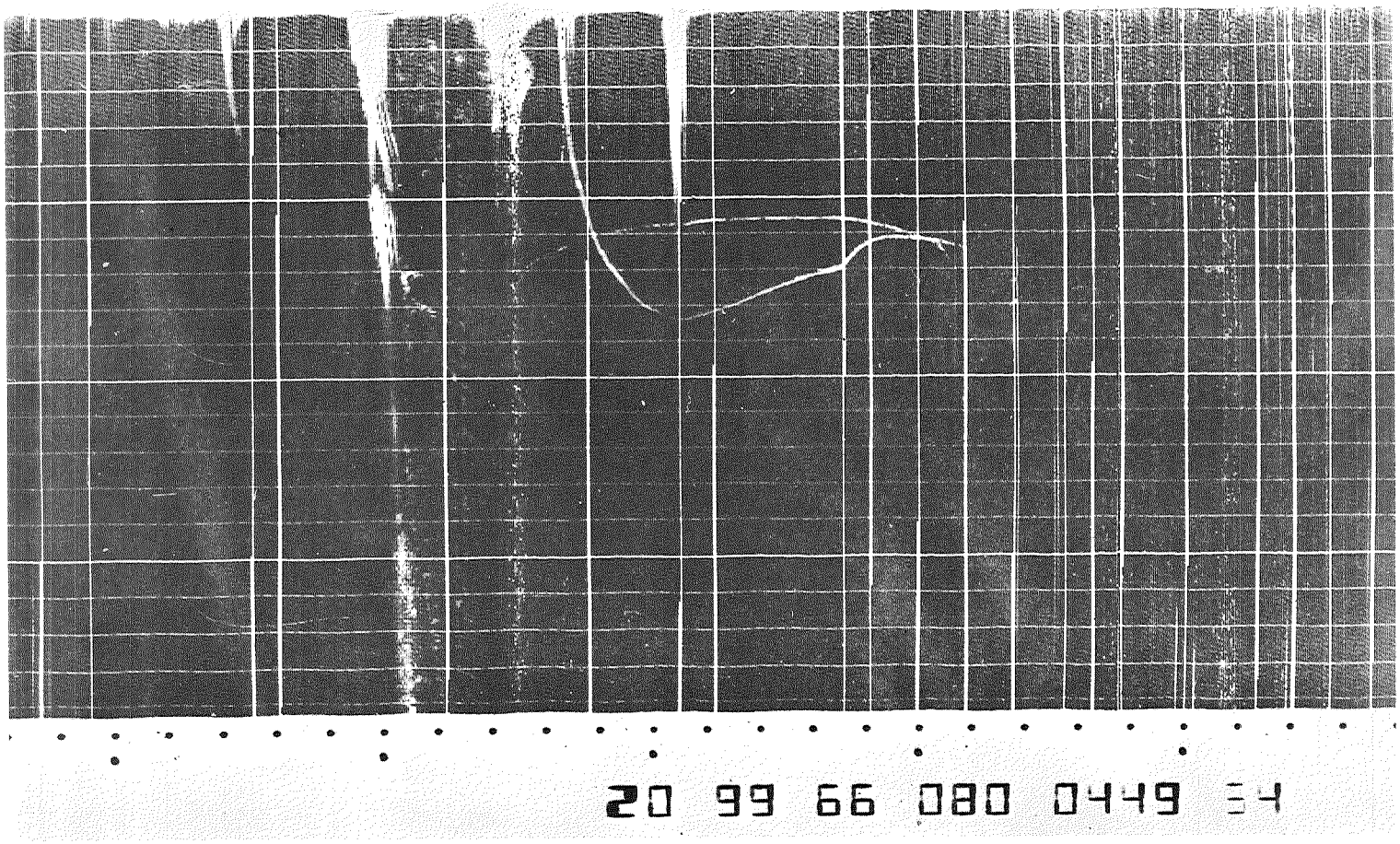


FIGURE 4-2 LOW ALTITUDE THIN LINE IONOGRAM

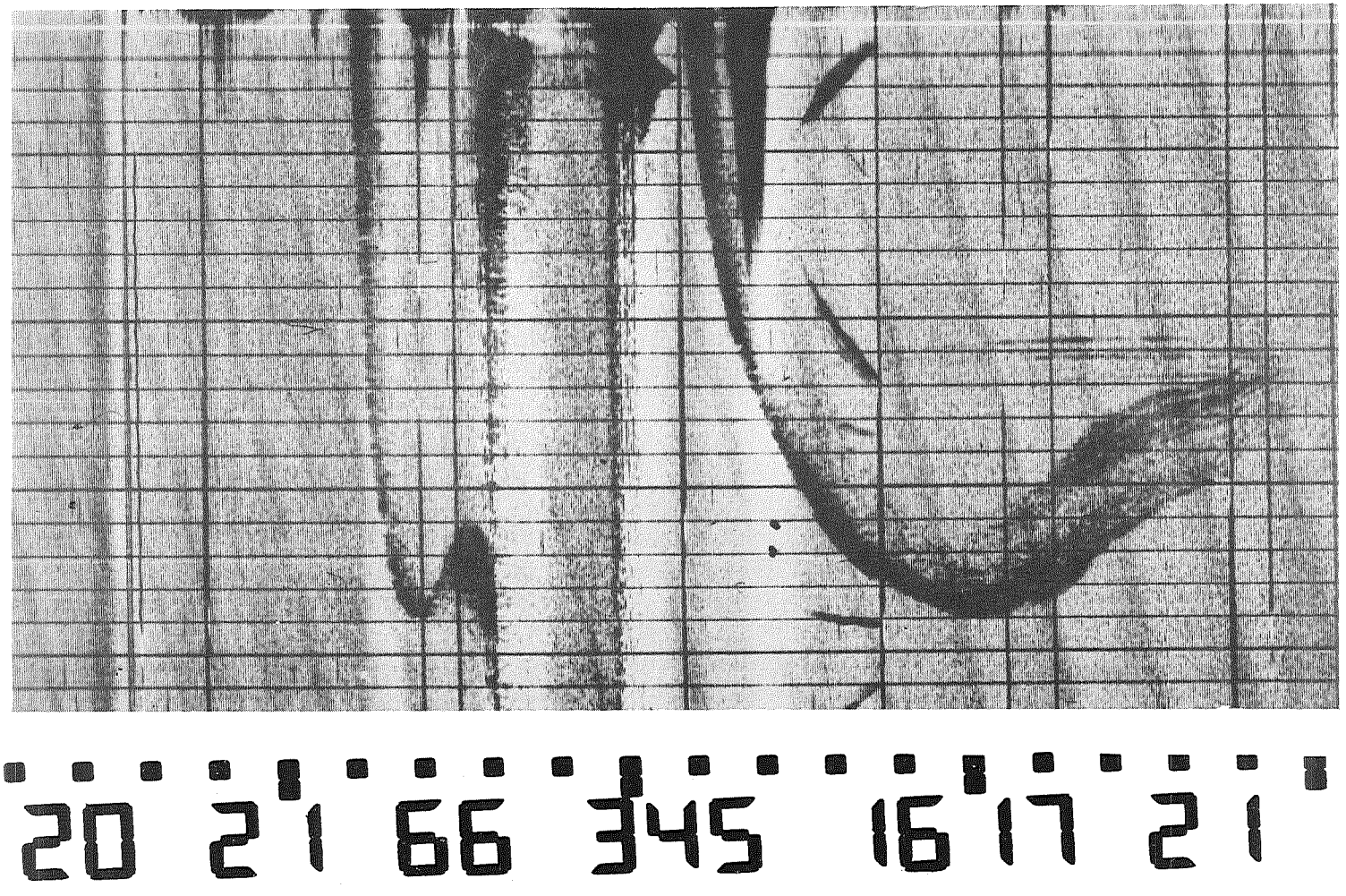


FIGURE 4-3 ALOUETTE II NEAR POLAR TOPSIDE SOUNDER IONOGRAM

When considering candidate digital computers for this application there are two general categories of digital computers that may be evaluated. These are the fixed-point machines (that are generally of the smaller variety) or, alternatively, the larger machines with a floating-point computation capability. The fixed-point machines perform computations with the presumption that the binary point (or in some cases the decimal point) is at some fixed position within all operands. As a consequence, the positioning of the binary point is the subject of a separate computation when performing calculations with wide dynamic ranges. Usually when a fixed-point machine is employed to perform scientific computation of the variety involved within the Topside Sounder Data Processing System, it is necessary to incorporate certain floating-point computation subroutines within the fixed-point computer's program. This software arrangement allows a fixed-point machine to accommodate calculations with wide dynamic range and precise resolution, but it takes much longer than the equivalent calculation done with floating-point hardware. One of the most significant disadvantages of fixed-point machines is their lack of speed when performing floating-point calculations. On the other hand, the more elaborate floating-point digital computers are more costly.

Processing each ionogram requires executing the $N_x(h)$ program at least once and it is expected that to assure high confidence in the resultant data, it will be standard practice to execute the inverse program at least once for each ionogram. Furthermore, in many

difficult cases it is anticipated that the N(h) programs and inverse program will be executed two or more times in the course of processing the data from one ionogram. These multiple executions are involved with a converging process until the $\overline{h_o'(f)}$ trace matches satisfactorily with the observed ordinary echo trace.

It appears that a reasonable estimate would be that the $N_x(h)$ and $\overline{h_o'(f)}$ programs will be executed on the average of 1.33 times for each processed ionogram. (On the average, every third ionogram will require two iterations.)

These electron density and inverse computations dominate the processing burden borne by the Central Processor. It is assumed that the system Central Processor will have the organization of the typical modern digital computer, whereby certain memory banks may be assigned to buffer throughput operations, and the input/output operations through this dedicated memory bank will not interfere with program execution conducted in another independent memory bank. With this general type of computer architecture in mind, it is then valid to dismiss concurrent throughput as a significant interference with computational program execution; e.g., digitized video information may be throughput from the peripheral analog-to-digital converter to a peripheral magnetic disc, via a selected bank of magnetic core memory while concurrent N(h) computation might be in progress independently within another memory bank.

The digitized telemetered video input operations and display refresh operations involve a high volume of data; however, these operations are to be fully buffered and do not represent a significant interference with the computation load.

The operator conversations are for the most part relatively simple functions to perform, oftentimes involving less than 300 machine cycles and are executed usually in response to operator action. Due to the inherently slow speed of the operator, it is not expected that operator-initiated activities would recur more rapidly than a few times per second. Consequently, the critical operations that determine the system productivity are the dominating burden of computing N(h) and inverse h' solutions. All other non-buffered operations increase this primary load by no more than 2 or 3 seconds for each ionogram (including formatting the CRT refresh store).

In order to evaluate accurately the capacity of the available computers regarding this burden, it is necessary to select a real or hypothetical machine and perform detailed program analysis. One technique is to create a hypothetical composite computer repertoire reflecting typical capabilities of various computers that may be candidates. The results derived from this type of hypothetical composite computer evaluation do not necessarily reflect the execution time of any given computer, but will provide usually a fairly accurate

estimate of what might be expected from a typical computer of the same class. An alternate, more direct technique, is to select a particular computer that is representative of the machines in its class, and conduct the program analysis using the particular machine's repertoire and execution rate.

In this study, it was concluded that acceptably accurate results could be derived via the latter technique. Accordingly, for the fixed-point case the available small-scale digital machines were reviewed. The machines considered included:

Honeywell DDP 516

DEC PDP 9

SDS Sigma 2

EMR 6130

Some of these machines offer features that may not be available on others. One machine may have a somewhat more powerful repertoire, perhaps, than some of the other machines considered in the survey. However, in the main, there are no outstanding performance differences recognized among these machines. (Admittedly, by selecting carefully tailored test problems, it might be shown that one machine might execute certain test problems, say, 40 percent faster than another machine.)

The SDS Sigma 2 Computer was used as an analysis test model for a fixed-point machine. This particular computer was not necessarily judged as the best computer for the task, but merely the SDS Sigma 2 Computer is suitably representative of its class of commercially available small-scale, 1 microsecond, fixed-point general-purpose digital computers.

4.3 FLOATING-POINT "MODEL" COMPUTER

A variety of floating-point scientific computers are available on the market that are manufactured by such major computer firms as IBM, Control Data, RCA, General Electric, Honeywell, Scientific Data Systems, Sperry Rand, Digital Equipment Corporation, etc. A brief summary of the market reveals that the SDS Sigma 5 appears to be one of the lowest priced floating-point machines suitable for this task. Accordingly, the SDS Sigma 5 was used as a test vehicle for analyzing the system computational capacity. It is not intended here to imply that the Sigma 5 is the recommended machine. It is, however, considered suitably representative of available low-cost, floating-point machines for these evaluating purposes.

4.3.1 CRITICAL PROGRAM RUN TIME (FLOATING POINT)

Source decks for the N(h) program, as well as the inverse program, were keypunched and then compiled on a Sigma 5 computer and listed in machine language. Table IV-1 shows the run times for the main programs and subroutines. As indicated in this table, the

TABLE IV-1

ROUTINE	FIXED POINT		FLOATING POINT		EXECUTION TIME LIBRARY ROUTINES μs	TOTAL EXECUTION TIME μs
	INST. EXECUTED	EXECUTION TIME μs	INST. EXECUTED	EXECUTION TIME μs		
MAIN	12,728	38,164	1,354	10,832	30,540	79,536
TABLES	8,281	24,843	67	536	68,400	93,779
INVAR	16,268	48,804	3,214	25,712	40,480	114,996
START	448	1,344	59	472	2,140	3,956
LINES	996	2,988	146	1,168	3,680	7,806
INTEG	5,864	17,592	1,048	8,384	18,380	44,356
CARMEL	112	336	29	232	1,560	2,128
FIELDG	13,493	40,479	881	7,048	10,725	58,252
FIELD	16,460	49,380	1,094	8,752	90,240	148,372
EXORD*	35,241	105,723	14,236	113,888	462,789	682,400
SUB-TOTALS	109,891	329,653	22,128	177,024	728,934	1,235,611
FIELD and FIELDG are executed once per point via EXORD routine. Assume 15 points . . .		1,347,885		237,000	1,514,475	3,099,360
TOTAL		1,677,538		414,024	2,243,409	4,334,971

Table showing Sigma 5 Instructions and Time for $N_x(h)$ Profile Computations. 3μs Fixed Point; 8μs Floating Point.

* Average of 4 iterations in EXORD.

average fixed-point instruction execution time is taken as 3 microseconds, while the average floating-point instruction is estimated at 8 microseconds. From these tables, it will be noted that the estimated total execution time for the N(h) profile program is 4.33 seconds.

Table IV-2 indicates that the total execution time for the Sigma 5 to perform the inverse calculation is 0.71 seconds.

Therefore, the sum of the total time required to calculate a 15-lamination N(h) profile and a comparable inverse computation, assuming 4 iterations per lamination, is approximately 5.1 seconds. Assuming that the average ionogram will require repeating this process 1.33 times (about one out of three ionograms will require repeating the process twice), the total execution time for these computations will be in the order to 6.6 seconds. Allowing an additional 3 seconds to format the Refresh Store and to service the operator-initiated requests, the total execution time for a 15-point (15 laminations) ionogram will be less than 10 seconds.

4.3.2 CRITICAL PROGRAM RUN TIME (FIXED POINT)

The tables derived from the compiled Sigma 5 programs were employed to determine the execution time for the representative fixed-point computer. The technique

TABLE IV-2

ROUTINE	FIXED POINT		FLOATING POINT		EXECUTION TIME LIBRARY ROUTINES μs	TOTAL EXECUTION TIME μs
	INST. EXECUTED	EXECUTION TIME μs	INST. EXECUTED	EXECUTION TIME μs		
INVERSE	207	621	-	-	40,000	40,621
O TRACE (15 lami-nations)	51,236	153,708	30,265	242,120	276,000	671,828
TOTALS		154,329		242,120	316,000	712,449

Table of Execution Time for Sigma 5 to Perform Inverse $N_x(h) \longrightarrow \overline{h_o'(f)}$ Transformation

TABLE IV-3

ROUTINE	FIXED POINT		FLOATING POINT		EXECUTION TIME LIBRARY ROUTINES μs	TOTAL EXECUTION TIME μs
	INST. EXECUTED	EXECUTION TIME μs	INST. EXECUTED	EXECUTION TIME μs		
MAIN	12,728	38,164	1,354	324,960	37,643	414,849
TABLES	8,281	24,843	67	16,080	68,400	117,671
INVAR	16,268	48,804	3,214	771,360	634,611	1,474,257
START	448	1,344	59	14,160	10,839	26,850
LINES	996	2,988	146	35,040	10,664	49,834
INTEG	5,864	17,592	1,048	251,520	245,434	521,458
CARMEL	112	336	29	6,960	6,680	14,117
FIELDG	13,493	40,479	881	211,440	72,658	338,951
FIELD	16,460	49,380	1,094	262,560	92,406	421,900
EXORD*	35,241	105,723	14,236	4,233,840	6,063,536	10,452,576
SUB-TOTALS	109,891	329,653	22,128	6,127,920	7,242,871	13,832,463
FIELD and FIELDG are executed once per point via EXORD routine. Assume 15 points . . .		1,347,885		7,110,000	2,475,960	11,412,765
TOTAL		1,677,538		13,237,920	9,718,831	25,245,228

Table showing Sigma 2 Instructions and Time for $N_x(h)$ Profile Computations. 3μs Fixed Point; 240 μs Floating Point.

* Average of 4 iterations in EXORD.

TABLE IV-4

ROUTINE	FIXED POINT		FLOATING POINT		EXECUTION TIME LIBRARY ROUTINES μs	TOTAL EXECUTION TIME μs
	INST. EXECUTED	EXECUTION TIME μs	INST. EXECUTED	EXECUTION TIME μs		
INVERSE	207	621	-	-	162,000	162,828
O TRACE*	51,236	153,708	30,265	7,263,600	1,340,000	8,603,600
TOTALS		154,329		7,263,600	1,502,000	8,765,600

* 15 laminations

Table of Execution Time for Sigma 2 to Perform Inverse $N_x(h) \longrightarrow \overline{h_o'(f)}$ Transformation

involved was to calculate a performance ratio for the Sigma 2 versus the Sigma 5. These comparisons are outlined below:

Floating Point Operations

Sigma 5 Floating Point Add/ Subtract Short	6.0 μsec
Sigma 5 Floating Multiply Short	10.0 μsec
Sigma 2 Floating Add/Subtract (Subroutine)	210.55 μsec
Sigma 2 Floating Multiply (Subroutine)	226.35 μsec

The ratio between a Sigma 2 and a Sigma 5 for a floating-point add is $210.5/6 \cong 35$.

The ratio between the Sigma 2 and the Sigma 5 execution time for a floating-point multiply is therefore $226/10 \cong 23$.

Considering the multiply-add mix within this program, it is acceptable to set the ratio for floating operations between Sigma 5 and Sigma 2 at 30:1.

Thus, the tabulations for the computational times using the Sigma 2 were estimated by multiplying Sigma 5 floating point times by a factor of 30 and appending the estimated library functions times.

This analysis yields a computation time of 25.25 seconds for N(h), and 8.77 seconds for the inverse $N_x(h) \longrightarrow h_o'(f)$ calculations for a total of 34.0 seconds for one iterative cycle. This is the time for the Sigma 2 when assuming 15 laminations with an average of 4 iterations in each lamination solution.

An additional 3 seconds is required to format the CRT refresh display and service operator requests. The total machine time then is 37 seconds to process each ionogram.

Assuming that the average ionogram will require a repeat of the closed-loop process 1.33 times the total execution time per ionogram for these computations will average approximately 50 seconds.

4.4 IONOGRAM PROCESSING CAPACITY

Experiments indicate that the minimum operator time to interpret a displayed ionogram and designate a selected trace with the cursor is about 10 seconds. With allowances for fatigue and other operator delays, a practical average interval for this manual track selection is 20 seconds. An additional 5 seconds may be allocated for the operator to confirm that the displayed correlation between the manually designated track and the X-trace is acceptable. Another 5 seconds is allowed to confirm that the correlation between the inverse $\overline{h_o'(f)}$ track agrees suitably with the O-trace.

These figures are presented in table IV-5 entitled, "Ionogram Processing Time--Manual Track Selection Mode (15 Laminations)". This table indicates (for these conditions) a production rate of 70 ionograms/hour for a floating-point system and 40 ionograms/hour for a fixed-point system.

An operating mode is described in section III wherein a model ionosphere is extrapolated from preceding ionogram data. Table IV-6, "Ionogram Processing Time--Extrapolated Model Ionosphere Mode (15 Laminations)" indicates that in this mode, ionogram production may increase to 124/hour for floating-point equipment and 45/hour for fixed-point equipment.

These estimates are predicated on ideal 15 lamination solutions. However, some solutions may involve occasionally 25 or 30 laminations. An average estimate is 21 laminations. Tables IV-7 and IV-8, representing 21-lamination solutions, indicate that, under these conditions, the ionogram processing rate becomes 67/hour for floating-point equipment and 31/hour for fixed-point equipment when operating in the manual track selection mode. Whereas, operating in the extrapolated model ionosphere mode increases production to 112/hour for floating-point equipment and 33/hour for fixed-point equipment.

At lower altitudes many passes may be expected to produce simple, thin-line, easily interpreted ionograms. Also, oftentimes a contiguous set of ionograms are very

TABLE IV-5

IONOGRAM PROCESSING TIME--
MANUAL TRACK SELECTION MODE
(15 LAMINATIONS)

		OPERATOR TIME (SECS)	MACHINE TIME FLOATING POINT (SECS)	FIXED POINT MACHINE TIME (SECS)
1.	Format CRT refresh store	-	1	1
2.	Preview ionogram, select F_{xs}, scale X-trace	20	nil	nil
3.	Correlate manual track with echo pulses	-	nil	nil
4.	Confirm acceptable correlation between track and trace	5	-	-
5.	Compute $N_x(h)$	-	4.33	25.25
6.	Compute and display $\overline{h_o'(f)}$	-	.71	8.77
7.	Confirm acceptable correlation between $\overline{h_o'(f)}$ track and O-trace	5	-	-
8.	Housekeeping and operator services	-	2	2
	TOTALS	30	8.04	37.04

FLOATING-POINT EQUIPMENT

Operator time	30 secs
Machine time	8 secs
	38 secs

Rework allowance
$1.33 \times 38 \simeq 51$ secs

Production rate: 70/hour

FIXED-POINT EQUIPMENT

Operator time	30 secs
Machine time	37 secs
	67 secs

Rework allowance
$1.33 \times 67 \simeq 90$ secs

Production rate: 40/hour

TABLE IV-6

IONOGRAM PROCESSING TIME--
EXTRAPOLATED MODEL IONOSPHERE MODE
(15 LAMINATIONS)

		OPERATOR TIME (SECS)	MACHINE TIME FLOATING POINT (SECS)	FIXED POINT MACHINE TIME (SECS)
1.	Format CRT display store	-	1	1
2.	Select F_{xs}	3	-	-
3.	Compute B, θ		*	*
4.	Compute $\overline{h_x'(f)}$	-	.71	8.8
5.	Correlate $\overline{h_x'(f)}$ track and echos	-	nil	nil
6.	Confirm proper correlation $\overline{h_x'(f)}$ and X-trace	5	-	-
7.	Compute $N_x(h)$	-	4.33	25.2
8.	Compute $\overline{h_o'(f)}$ and display track		.71	8.8
9.	Confirm acceptable match between $\overline{h_o'(f)}$ track and O-trace	5	-	-
10.	Housekeeping and operator services	-	2	2
	TOTALS	13	8.75	45.8

FLOATING-POINT EQUIPMENT		FIXED-POINT EQUIPMENT	
Operator time	13 secs	Operator time	13 secs
Machine time	8.75 secs	Machine time	45.8 secs
	21.75 secs		58.8 secs
Rework allowance 1.33 x 22 $\cong$ 29 secs		Rework allowance 1.33 x 59 $\cong$ 79 secs	
Production rate: 124/hour		Production rate: 45/hour	

*This calculation is introduced here only to show logical sequence, actual machine time is included within item 7.

TABLE IV-7

IONOGRAM PROCESSING TIME--
MANUAL TRACK SELECTION MODE
(21 LAMINATIONS)

		OPERATOR TIME (SECS)	MACHINE TIME FLOATING POINT (SECS)	FIXED POINT MACHINE TIME (SECS)
1.	Format CRT refresh store	-	1	1
2.	Preview ionogram, select F_{xs}, scale X-trace	20	nil	nil
3.	Correlate manual track with echo pulses	-	nil	nil
4.	Confirm acceptable correlation time between track and trace	5	-	-
5.	Compute $N_x(h)$ profile	-	6.26	40.3
6.	Compute and display $\overline{h_o'(f)}$	-	.99	12.3
7.	Confirm acceptable match between $\overline{h_o'(f)}$ track and O-trace	5	-	-
8.	Housekeeping and operator services	-	2	2
	TOTAL	30	10.25	55.6

FLOATING-POINT EQUIPMENT

Operator time 30 secs
Machine time 10.25 secs
40.25 secs

Rework allowance
1.33 x 40.25 $\cong$ 54 secs

Production rate: 67/hour

FIXED-POINT EQUIPMENT

Operator time 30 secs
Machine time 55.6 secs
85.6 secs

Rework allowance
1.33 x 85.6 $\cong$ 114 secs

Production rate: 31/hour

TABLE IV-8

IONOGRAM PROCESSING TIME--
EXTRAPOLATED MODEL IONOSPHERE MODE
(21 LAMINATIONS)

		OPERATOR TIME (SECS)	MACHINE TIME FLOATING POINT (SECS)	FIXED POINT MACHINE TIME (SECS)
1.	Format CRT display store	-	1	1
2.	Select F_{xs}	3	-	-
3.	Compute B, θ		*	*
4.	Compute $\overline{h_x'(f)}$	-	.99	12.3
5.	Correlate $\overline{h_x'(f)}$ track and echos	-	nil	nil
6.	Confirm proper correlation $\overline{h_x'(f)}$ and X-trace	5	-	-
7.	Compute $N_x(h)$	-	6.26	40.3
8.	Compute $\overline{h_o'(f)}$ and display track		.99	12.3
9.	Confirm acceptable match between $\overline{h_o'(f)}$ track and O-trace	5		
10.	Housekeeping and operator services	-	2	2
	TOTAL	13	11.24	67.9

FLOATING-POINT EQUIPMENT

Operator time 13 secs
Machine time 11.24 secs
24.24 secs

Rework allowance
1.33 x 24.2 $\cong$ 32 secs

Production rate: 112/hour

FIXED-POINT EQUIPMENT

Operator time 13 secs
Machine time 67.9 secs
80.9 secs

Rework allowance
1.33 x 80.9 $\cong$ 108 secs

Production rate: 33/hour

*This calculation is introduced here only to show logical sequence, actual machine time is included within item 7.

similar with only gradual changes from one to the next. In these simple, gradually changing situations, it should be unnecessary to check each inverse $\overline{h_o'(f)}$ track in comparison with the observed O-trace. After a few ionograms check satisfactorily, this test may be deleted for these simple non-ambiguous traces. A spot check near the end of the pass may be a worthwhile precaution.

With a 21 lamination profile, deleting the inverse computation and the operator comparison reduces the operator time 5 seconds, the floating-point machine time 0.99 seconds, and the fixed-point machine time 12.3 seconds for each ionogram. Accordingly, during the major portion of many low-altitude passes with 21 data points per ionogram, the processing rate can be accelerated to 200/hour for floating-point equipment and 57/hour for fixed-point equipment. These figures naturally do not include a rework allowance.

From these analyses emerge a range of production capacities for various quality ionograms. The capacity of a system with a floating point processor ranges from 67/hour to 200/hour;[1] while a system equipped with a fixed-point processor is expected to offer 31/hour to 57/hour.

---

[1] It is important to note that the machine is often waiting for the operator to complete her contribution. With a floating-point computer, the processor is waiting from 45% to 79% of the time, e.g., where 28 seconds is allocated to process an ionogram, 20 seconds are relatively inactive while waiting on the operator. Less than 50% of the processor's actual capacity is committed to processing data from analog magnetic tape, and machine time is available for additional tasks such as processing filmed ionogram data (see Section VII). Therefore, another operator, at a peripheral film digitizing console time sharing the same computer, could be processing filmed ionograms with negligible interference.

The various production rates for processing ionograms from magnetic tape are optimistically based on the estimated best performance for a team of two operators. One operator serves as the incidental system equipment operator, logging incoming tapes, rewinding and reloading tapes, prepositioning the next analog tape, servicing the printer and plotter, etc. The other operator is concentrating exclusively on the real-time ionogram console. This does not necessarily imply that this operator is continuously absorbed and will tire quickly. On the contrary, the routine processing procedures include inherent regular periods when the operator will be waiting for the system to perform calculations.

With consideration for contingencies, it appears possible to maintain an average processing rate of more than 60 thin-line ionograms per hour with a system equipped with a floating-point computer, and at least 30 thin-line ionograms per hour with a fixed-point computer.

Complex high-altitude ionograms are another matter. Operator cogitation time will increase somewhat, but it is not intended that undue time be spent by the operator evaluating many traces. Instead, a likely candidate trace is selected and a sequence of converging iterations is initiated until the man-machine team agrees on a solution. The operator pre-examination time will increase only modestly over thin-line cases. However, the rework allowance will increase significantly. It may take four

or five iterations of the mixed mode operations to process the first ionogram in a pass. The next few ionograms may require two iterations each. It is expected that rework normally will diminish as more experience is gained with a given pass.

It is estimated that 12 extra iterations will be required in a 20-ionogram pass. This suggests a rework allowance of 1.6. Consequently, the estimated average ionogram processing capacity for high-altitude ionograms is 45 per hour for floating-point equipment and 20 per hour for a system with a fixed-point processor. (All run time estimates in this section are based on N(h) and $\overline{h_o'(f)}^p$ programs presently in use and do not consider potential program enhancement via new software procedures.)

4.5 STORAGE REQUIREMENTS

The following is a tabulation of processor storage requirements for the proposed Semi-Automatic Data Processor.

STORAGE REQUIREMENTS

1 byte = 8 bits

1. DISC

A-Scan and Gray Scale Data	1.62 million bytes
(6 bits) (2 bits)	2 ionograms
	840 lines/ionogram
	960 samples/line (4800 KM)
	1 sample/5 KM
Temporary Storage	230,000 bytes
Program Storage	150,000 bytes
Total Disc Storage	2,000,000 bytes (nominal)

2. CORE MEMORY

Program Storage	10,000 bytes (Overlay techniques used)
Data Storage	
Refresh Store	27,000 bytes, 1 ionogram
Spot Store	1,800 bytes

Track Display Stores (6)	4,800 bytes
A-Scan Store for Display, 3 lines	3,000 bytes
Sub-Total	46,600 bytes
I/O Buffers	4,096 bytes
Disc (2 buffers)	2,048 bytes
Digitized Inputs	
A-Scan Data	2,048 bytes
Film Reader Storage	3,600 bytes
Program (approx.)	2,400 bytes
Data	1,200 bytes
Display Store	
X, O, Z 100 10-bit values =	600 bytes
Inverse Display Store	
X, O, Z 100 10-bit values =	600 bytes
Sub-Total	7,696 bytes
Total	54,296 bytes
Modular Core Memory Size	65,536 bytes
Memory for Future Expansion	11,240 bytes

4.5.1 STORAGE REQUIREMENT SUMMARY

Core memory requirements may be met with 65,536 bytes of storage. A 2,000,000 byte rapid access disc will serve adequately for mass storage.

4.6 TIME SHARE

Preceding portions of this section reveal a greater than 2:1 ratio between the capacity of floating-point equipment and fixed-point equipment. One compromise system configuration is a time-share type of system wherein the N(h) and $\overline{h'(f)}$ computation task would be transferred to a separate floating-point computer while a fixed-point machine serves as the controller within the system. This arrangement relieves the control computer of N(h) and $\overline{h'(f)}$ computations but naturally requires a moderately broadband link between the two computers (a full-duplex 2400-baud conventional telephone digital modem would suffice).

The immediate attraction of this scheme is economic. The price difference between the study candidate fixed-point and floating-point machines is about $120,000. If a large floating-point machine happens to be available via a link to some other facility, then a time-share scheme may be feasible. The limiting characteristic is the critical need for rapid turnaround, i.e., the operator cannot abandon a given ionogram until a final solution is at hand for visual comparison. Therefore, the process is "hung-up" until the remote time-shared floating-point machine returns the solutions. In order to be practical, the ionogram processing system must

have a "sledge-hammer" priority over the other work that the floating-point machine might be doing.

A number of commercial time-share bureaus were queried in connection with this type of service. They unanimously stated that there is no interest in servicing one customer with a 5-10 second floating-point task at around one-minute intervals while guaranteeing, say, 30-second turnaround. Relaxing the priority demands to 2-minute turnarounds did not change their viewpoint.

If we disregard commercial time-share services, it appears that time-share operations might be practical in a special NASA facility situation where the administrative relationship was such that a sophisticated real-time monitor could be resident in another NASA remote floating-point machine. Further, the ionogram system would require absolute authority to sieze control (within seconds after demand) throughout each working day of the year. In effect, the ionogram processing system dictates the schedule for the remote machine room.

In summary, the practicality of a time-share arrangement is more of an administrative question than technical question, and is outside the scope of this report.

SECTION V

SOFTWARE SYSTEM DESIGN

5.0 GENERAL

The software system will be dynamic, with improvements introduced as more experience is gained. The operating facility will be responsible for the creation and maintenance of the software system. This section outlines the level of effort estimated for this program.

A preliminary breakdown of the software tasks in support of the Semi-Automatic Ionogram Data Processor reveals six distinct areas of effort. These areas are:

(1) Executive Program
(2) Acquisition Program
(3) Man-Machine Communication Program
(4) Computational Programs
(5) Output
(6) Film Digitizer Interface

The areas listed above can further be broken down as more detailed analysis is applied to the tasks. This is especially true for the area of man-machine communication techniques. The other areas are defined sufficiently in present ionogram processing methods, or have been incorporated in recent computer-controlled data systems.

The organization of the software system must stress modularity. Modularity will facilitate replacing or modifying parts of the total software system. This is a basic requirement, since the Ionogram Data Processing System will be undergoing constant revisions in a learning cycle.

Detailed data storage and retrieval techniques are to be studied. For the efficient operation of this system, all data must be readily accessible when required for processing or display. During the man-machine communication phases, the program will require rapid access to any line of A-scan, gray scale and pulse data. Poor data access will result in an undesirable delay in responding to operator requests.

5.1 EXECUTIVE PROGRAM

Although this software entity has a sophisticated title, it actually is not a difficult programming task. Its function is to schedule the subprograms in their appointed operating cycle. The Executive Program will always reside in memory. It will retrieve routines (overlays) from the mass storage device (disc) as they are required. For example, it will not initiate the computation of N(h) until the man-machine conversational part of the system or film station processing has designated a set of h'(f) input points.

Part of the function of the Executive Program is to respond to interrupts. For interrupts it will merely interpret as to cause and schedule the correct action by the appropriate routine.

This program has a dedicated function of controlling the flow of ionogram processing steps. It will not have foreground-background general processing capabilities.

5.2 ACQUISITION

The Acquisition Program will handle all tasks relating to the input of data from the analog tape. As such, it

will have the capability to start-stop search the tape for the desired time slices. This range time information is maintained by the program.

The program will control the bookkeeping relating to the transfer of data from the analog subsystem to computer memory, and eventually to disc. It will affix all data tags required to facilitate the rapid retrieval of this data at the time of processing.

The program will operate under command of the executive program--acquiring the data for an ionogram when the executive determines that there is room for the next ionogram to be processed. Feedback to the Executive Program will relate to the ionogram being input, or some error such as the data desired was not on the source tape.

5.3 MAN-MACHINE COMMUNICATION SOFTWARE

This phase of the ionogram processing cycle has to do with determining the location of a sufficient number of points to define the X-trace or O-trace, or perhaps the Z-trace. As such, this phase can be defined as the hub of the system. It is this task which has the greatest impact on measuring the capability of the system to process ionograms. In other words, the quicker the traces can be defined the faster the ionogram can be analyzed.

It is this phase of the processing cycle which requires that the proposed system be designated as "semi-automatic." For many ionograms, especially high altitude ionograms,

the computer will require the aid of the operator in locating the traces and will require the operator's appraisal of computer-derived results. With this in mind, the software which is applicable to this phase must not only contain input/output routines for conversation with the operator, but these routines must have error-checking and recovery schemes in order to guard against the possibility of losing the coherency of the total procedure. The software must contain routines to sample status switches on the operator's console and check for inadvertent contradictions.

The software must include an efficient scheme for data management. It will be most beneficial to be able to quickly correlate cursor position on the screen to line numbers on the disc. It should be possible to access A-scan data from disc in a minimal period of time.

The software must be able to expand designated areas of the CRT ionogram picture. This means a retransformation of the compressed data representation of the ionogram picture in the Refresh Store.

The main function of this software phase is the task of trace identification. This task may be performed by several different methods categorized by the degree of operator participation. This function will encompass a capability to correlate data input vs. the original A-scan data, the use of interpolation algorithms, and the possibility of curve-fitting used in extending or joining known portions of the X, O or Z traces.

The software must be able to link with the computational programs in order to transfer h'(f) data points for N(h) computation, and receive $\overline{h'(f)}$ data points from the inverse program for display to the operator.

The software must be written in a master routine-subroutine form. This will facilitate additions, replacement and deletions of the subroutines. It is this area of software which will be most affected by changes suggested after system utilization.

5.4 COMPUTATIONAL PROGRAMS

These are the forward and inverse programs[1] for calculating N(h) and $\overline{h'(f)}$. The programs already exist and are operational for the large scale Direct Coupled System at NASA/ARC.

These programs would have to be extensively modified (maybe recoded) to accomplish three objectives:

1. Operate as a unit
2. Segment the programs to conserve memory
3. Introduce linkage via executive program to pick up input from man-machine phase and leave results for output programs

Since it is expected that this program will be written in the FORTRAN language, there may be work effort extended in incorporating the object output from compilations into the overall system.

---

[1] See footnotes page 4 Section III

5.5 OUTPUT

These programs will print and/or plot the results from the N(h) or the inverse calculations. The actual output may be to a magnetic tape in lieu of an on-line printer and plotter. The output programs could also handle the accumulation of several N(h) computations and then cause the output of a "contour plot."

5.6 FILM IONOGRAM DATA PROCESSING

The software for a film ionogram data processing system with CRT display will perform the following functions:

1. Accept digital data inputs from the optical data reader.
2. Perform coordinate transformations based on initial calibration data inputs.
3. Set up the necessary frequency marker and range marker coordinates on the CRT, and display scaled and computed data points.
4. Display a movable cursor spot on the CRT that continuously follows the cursor position of the data reader.

This software provides the conversational mode type of operation that is essential for closed-loop operation. A detailed discussion of film ionogram data processing is contained in Section VII.

5.7 DATA COMPRESSION

Data compression is a software function of the display program that is used as a means of conserving core memory. Gray scale data in disc memory can be compressed in

two ways in order to minimize the size of the Refresh Store:

1. Editing out certain entities of a data class, e.g. taking every other line of gray scale data and/or every other picture element in a line of data.

2. Take advantage of certain redundant characteristics of ionogram picture data, e.g. when the gray scale data is constant for many consecutive elements, record only the positions where it changes.

Without data compression it would be necessary to retain, in memory, a mirror image of the ionogram picture on the CRT. A 500 line display, with 400 elements per line, contains 200,000 elements (spot positions). With a 4-level gray scale, each picture element is represented by a 2-bit GS-word. A mirror image in memory for this display would require 50,000 8-bit bytes.

Data compression based on gray scale redundancy should provide a memory saving of at least 2:1. However, it requires additional complexity in the CRT interface hardware which now must interpret outputs from computer memory to determine whether they are data or instructions.

Software is required to generate the compressed data format. This portion of the display software could be executed immediately after acquisition as a second part of the acquisition program, with the data stored on disc in temporary storage while the preceding ionogram is being processed.

5.8 SOFTWARE IMPLEMENTATION

This paragraph discusses a plan for implementing the required software for the recommended design of a Semi-Automatic Topside Sounder Data Processor (SATADP). All software systems must (at least should) go through four phases:

1. Analysis and Design
2. Coding
3. Checkout
4. Documentation

5.8.1 ANALYSIS-DESIGN

In the analysis-design portion the software load is broken down into the various subprograms. Storage is assigned on disc and in the computer core memory. The flow of information among the different software subsystems is defined, which leads to the preliminary design of the interfaces between the software entities. This portion of the software implementation task requires close liaison with the hardware systems contractor. This is most important when the system being programmed is custom designed to perform one dedicated task such as is the case here.

It is very important that the person(s) performing the analysis-design phase of the effort be the most experienced in all aspects of the total system design. He must be capable of seeing the "whole picture" and have a basic knowledge of the capabilities of hardware components so that he can effectively participate in hardware vs. software tradeoff discussions. The output of the design phase is the foundation upon which

all future software efforts will be supported, so it follows that this person must also be the "lead man" in the coding and checkout phases to ensure that independent efforts are directed toward the overall system design goal.

5.8.2 CODING

It is expected that the output of the analysis-design phase will break down the total task into separate but system-related efforts. An appropriate programmer is assigned to each of these subtasks, with the leadman coordinating the activity and possibly handling a section of the coding workload.

5.8.3 CHECKOUT

Each of the coding programmers will check out his assigned effort. After this is done, the total system is tied together and debugged as a unit. At this time the level of effort should be two men, leadman and senior programmer responsible for man-machine software task. Eventually this will phase down to one man to maintain the system with capability to draw on extra help as required.

5.8.4 DOCUMENTATION

This is really not a separate phase. The analysis-design phase will have preliminary documentation as a byproduct. Documentation of the software effort can proceed in parallel with coding and checkout, with a final wrap-up after completion of checkout.

5.8.5 SCHEDULE

The Project Plan located at the end of this section is a breakdown of the total effort. The schedule shows a continuation of checkout for the man-machine conversation, film digitizer station and software integration tasks. The numbers in parenthesis shows the additional weeks to completion. The level of effort involves 30 man months spanning nine calendar months.

It is important to note that the schedule as shown is for an initial system. It is expected that after experience has been gained there will be revisions and modifications to the original software in order to improve tracking algorithms, speed up data management, performing parallel work on separate ionograms and applying recursive techniques. Closed-loop processing, which is a recursive operation, will be employed for converging on the true location of the traces. Thus, even after the system is operational, there will likely be a continuing effort in software to test and then implement new and improved techniques. The purpose of this would be to minimize operator activity with the goal being a more automatic system with the desired feature of increasing ionogram processing productivity.

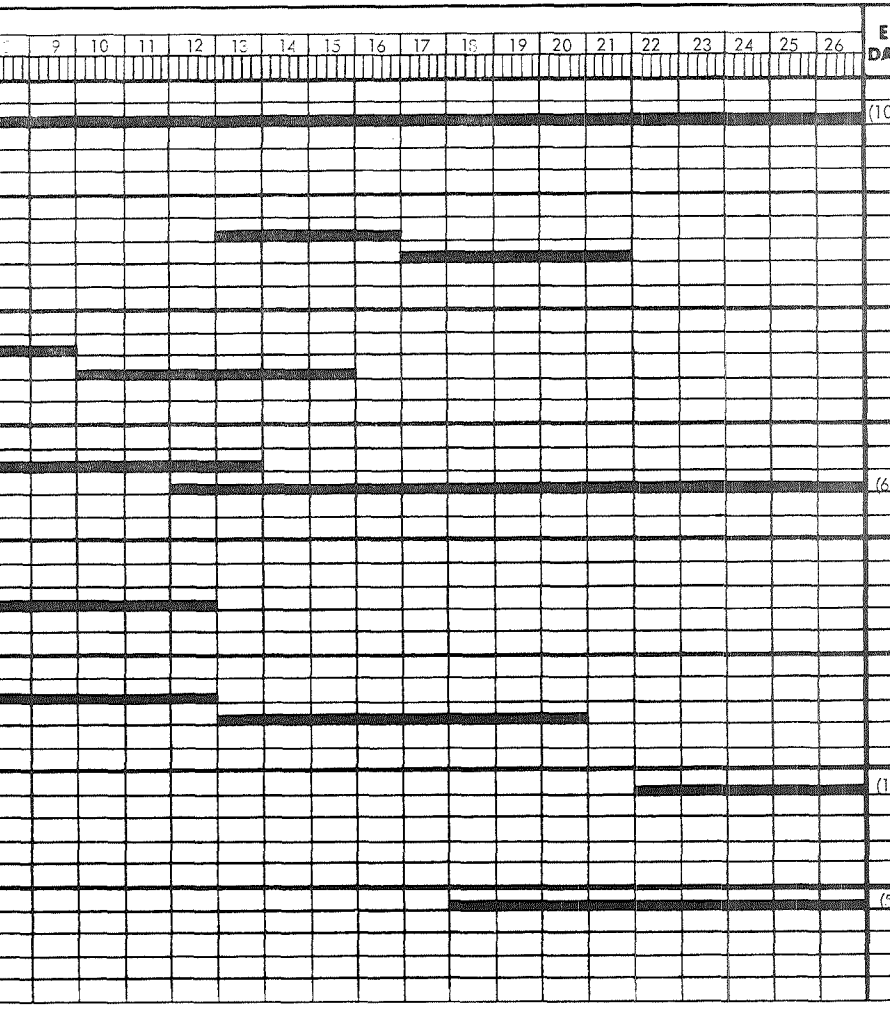
ASTRODATA INC.
240 East Palais Road, Anaheim, California

PROJECT PLAN

CUSTOMER NASA/ARC PROJECT MGR. _____ JOB NO. _____

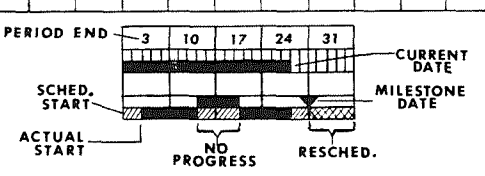
JOB DESCRIPTION TOPSIDE SOUNDER PROCESSOR SOFTWARE DATE _____ PAGE ____ OF ____

NO.	TASK DESCRIPTION	LOAD	EXT. DATE
1	ANALYSIS-DESIGN		
2	COORDINATION	36	(10)
3			
4			
5			
6	EXECUTIVE	9	
7	CODING		
8	CHECKOUT		
9			
10			
11	ACQUISITION	9	
12	CODING		
13	CHECKOUT		
14			
15			
16	MAN-MACHINE CONVERSATION	27	
17	CODING		
18	CHECKOUT		(6)
19			
20			
21	N(h) AND INVERSE	8	
22	CODING		
23	CHECKOUT		
24			
25			
26	OUTPUT	14	
27	CODING		
28	CHECKOUT		
29			
30			
31	SOFTWARE INTEGRATION	15	(10)
32			
33			
34			
35			
36	FILM DIGITIZING SYSTEM	14	(5)
37			
38			
39			
40			



REMARKS:

LEGEND:



PREPARED BY: A. Scardino DATE 7/20/67

APPROVED BY: R. G. Madsen DATE 8/3/67

APPROVED BY: _____ DATE _____

SECTION VI

PERIPHERAL EQUIPMENT

6.0 GENERAL

Detailed specifications for the various peripheral devices and subsystems are the subject of another document. However, it is useful here to introduce these equipments and outline their functions. All processor interface controllers are implied. For example, peripheral digital magnetic tape units are mentioned and it is implied without separate discussion that an appropriate input/output magnetic tape controller is also required.

6.1 ANALOG MAGNETIC TAPE SUBSYSTEM

This subsystem consists of two conventional analog magnetic tape units with narrowband and wideband FM demodulators.

6.2 RANGE TIMING SUBSYSTEM

A 36-bit NASA time code translator and tape search unit for each tape unit are required. Supplemental filtering is recommended for some poor quality time code recordings.

6.3 PHASE-LOCKED TIME BASE

The translation from the analog domain to the processor's digital domain must be performed with a time base that is referenced to the recording. The phase-locked time base is locked to the recorded reference signal and provides the clock signal for the analog-to-digital conversion process.

6.4 FREQUENCY MARKER SHAPER

The time of occurrence and the duration of frequency markers must be noted. The pulses are regularly distorted and serrated. The shaper serves to regenerate the frequency marker waveform.

6.5 ZERO AND SCALE SERVOS

The video signal is ac coupled and requires automatic dc restoration referenced to certain signal calibration pulses. The zero and scale servos normalize the video signal to a fixed offset and scale factor.

6.6 SYNCHRONIZER

The synchronizer observes the transmitted frame sync and line sync pulses, and maintains an accounting of intra-line elapsed time, to coordinate analog-to-digital conversion and calibration pulse identification. The synchronizer is capable of accelerated playback at four times real-time.

6.7 ANALOG-TO-DIGITAL CONVERTER (ADC)

The ADC produces 6-bit measurands at conversion rates up to 120,000 samples per second.

6.8 GRAY SCALE GENERATOR

The gray scale generator is a conversion matrix that converts the 64-level ADC samples to corresponding four shades of gray for the CRT real-time ionogram display.

6.9 I/O TELEPRINTER

The input/output teleprinter (or typewriter) is the regular control device installed on processors. It will be the standard unit for the selected processor.

6.10 CARD READER

Reliability is the most important concern for this unit. In practice, very little volume of data passes through this reader. Its principal function is during program debugging. Speed is not a prime consideration.

6.11 DISC FILE

The disc file will be a standard peripheral unit for the selected processor with a capacity of at least 2 million bytes. Retrieval time should be less than 67 milliseconds.

6.12 LINE PRINTER

A conventional line printer with a 600 line per minute capacity is adequate for this application.

6.13 INCREMENTAL PLOTTER

A standard 11-inch digital plotter operating at 300 points per second will meet the needs of this system.

6.14 DIGITAL MAGNETIC TAPE UNIT

The requirements imposed on the digital magnetic tape unit are modest. There are virtually no speed considerations because of the low data volume. The most important requirements are reliability and format compatibility with other computers within the operating facility.

6.15 FILM DIGITIZING CONSOLE

The magnetic tape mode of operation for processing ionograms does not saturate the processor continuously.

Machine time is available to process data from a film digitizing table concurrent with processing ionograms directly from analog magnetic tape. Section VII discusses more details of film-derived data processing requirements.

6.16 REAL TIME IONOGRAM CONSOLE

The suggested system in this report requires a "man in the loop." This means that a versatile operator console must be designed. The function of this console is to enable the operator to "steer" the software residing in the computer amongst several alternatives.

The console, and control software, must be designed so that it is not difficult to use yet maintains rigid interpretation by the computer of all operator activities. Versatility must be incorporated into the design of the console. Versatility is required since it cannot be expected that all forms of operator input will be known at the time of system design, but that system usage will point out requirements for additional controls on the part of the operator.

Currently the feeling is that the console has two types of inputs to the system processor: (1) demands which take the form of interrupts and (2) status which the computer can interrogate whenever it has alternative paths selectable by the operator.

6.16.1 KEYBOARD

Also to be connected as a byproduct of some demand inputs is a means of inputting data. This is envisioned as a numerical keyboard similar to a telephone "touch-tone" system. (See artist's concept of the console in figure 6-1.) The console operator presses the numerical buttons until the units digit has been entered. After completing this she actuates a "demand" type button which identifies to the computer what data value is being input, and causes the value to be accepted by the computer. It is advisable that as digit keys are struck by the operator the number being assembled is displayed until accepted by the computer via the demand input. This is similar to the operation of an adding machine whereby the addition of a number does not take place until the add key is struck.

Examples of the classes of input which would require the numerical keyboard would be:

1. Quality of ionogram indices. This would be a subjective appraisal by the operator.

2. Time information to control the search of the analog video tape.

3. Scaling and range information to cause displays of selected areas of each ionogram.

4. Identification parameters such as pass number, time bases, receiving station, etc.

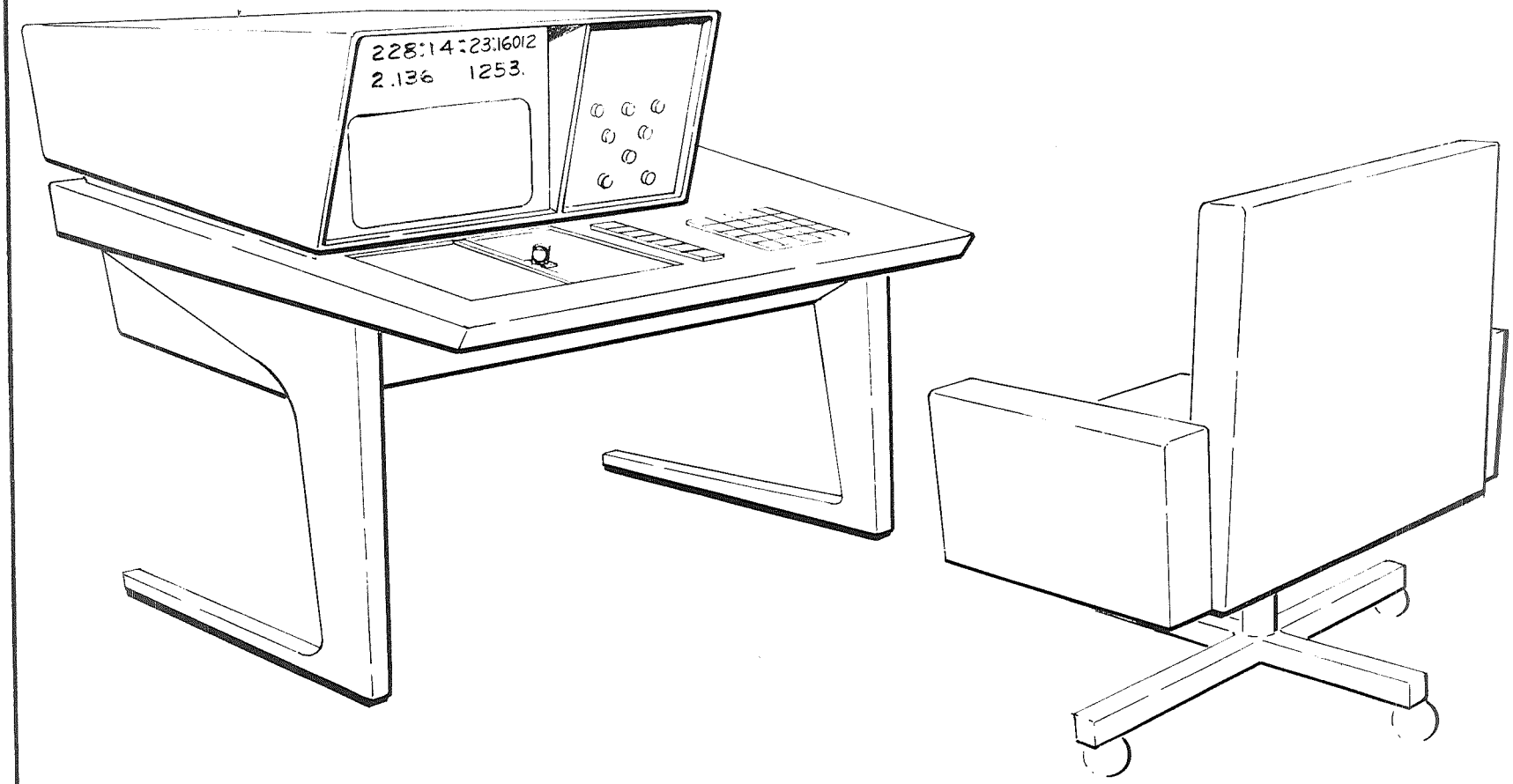


FIGURE 6–1 REAL TIME IONOGRAM OPERATOR'S CONSOLE

The general-purpose keyboard has the added advantage of not being limited to data inputs. It may be feasible to use the keyboard itself (with the addition of punctuation keys) to input commands. Then many operator commands can be input by striking the keys in a prescribed sequence. For example, the sequence 1,524 could mean that the pass number is 524, while 7,3 implies the assignment of a quality index of 3. In the examples shown, a comma is used to separate the data identifier from the data. As can be seen, there would not be any limit to the number of data classes. The procedure would be completely versatile since the software controls the interpretation of any defined input sequence.

6.16.2 DEMAND INPUTS

Certain demand type inputs do not require the input of an associated data value. An example of this would be REJECT which would cause the computer program to discard the ionogram currently being displayed on the screen. Other demand type inputs would be:

1. Compute $N_x(h)$, $\overline{h_o'(f)}$, $\overline{h_z'(f)}$.

2. Density profiles satisfactory -- output.

3. Data identification and inputs.

6.16.3 STATUS INPUTS

Status inputs are types which do not immediately enter the computer but are external switches which are input at the convenience of the program.

Examples of this type of input are:

1. Tape Direction (Forward-Reverse). Reverse tape drive is used for rewind only.

2. Trace Acquisition Mode.

   a. Manual - The operator by means of her control of the CRT cursor spot tells the computer where the X or O or Z trace is.

   b. Semi-Automatic - The operator inputs her opinion of where the X or O or Z trace is and the computer correlates this input versus the Pulse Store to obtain a fix on the X or O or Z trace.

   c. Automatic - The computer program locates the X or O or Z trace automatically.

Regardless of the mode of trace acquisition, the operator will be able to approve the points used for calculating the density profiles.

3. Output Options

   a. Plotting

   b. Print Formats

4. Cursor Spot Enable. This switch will exercise control on whether the position of the movable cursor spot is to be input or not. This may be either a hand operated or foot operated switch.

5. Display Options

a. Ionogram Refresh - Selects the option of displaying selected portions of the ionogram for CRT display.

b. Spot Display - Causes the display of the trace as input by the operator.

c. Track Display (X or O or Z) - Causes the display of data points the computer currently considers as representative of the X, O or Z trace.

d. Inverse Track Display (X or O or Z) - Causes the display of the data points computed by the inverse program

$$N(h) \longrightarrow \overline{h'(f)}.$$

e. Resonance Display - Causes the display of data points selected by the operator representing the frequency at maximum range of the resonances.

f. Scaled Data Points - Causes the display of the set of $h_x'(f)$ data points that are to be used in a subsequent N(h) calculation.

g. A-Scan Display - Causes three lines of A-scan data to be displayed vertically along with the ionogram. This display is used by the operator to locate manually the peak, leading edge or trailing edge of an echo pulse. The lines being displayed are selected according to the position of the cursor spot in the ionogram.

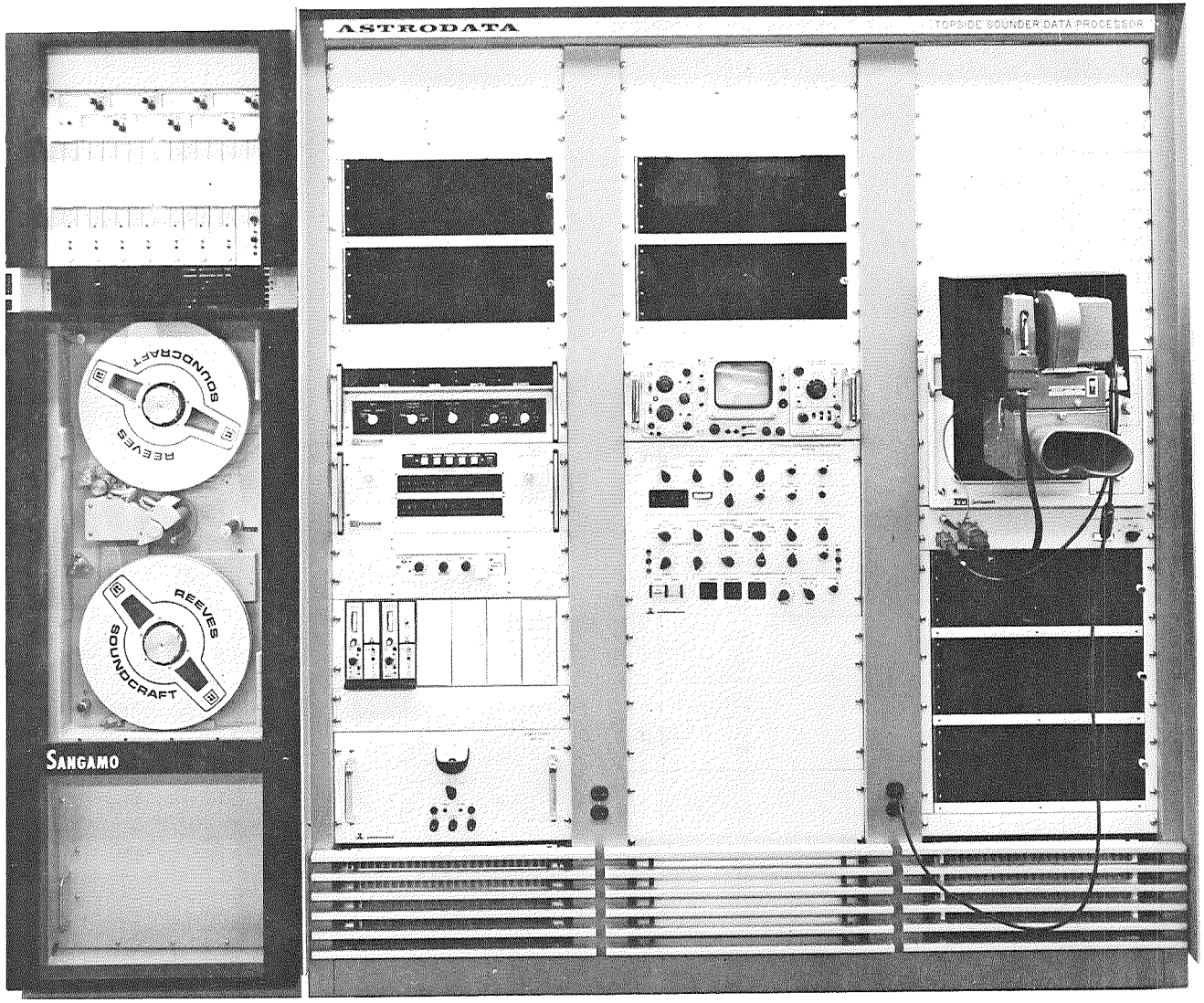
SECTION VII

TOPSIDE SOUNDER FILM IONOGRAM DATA PROCESSING SYSTEM

7.0 GENERAL

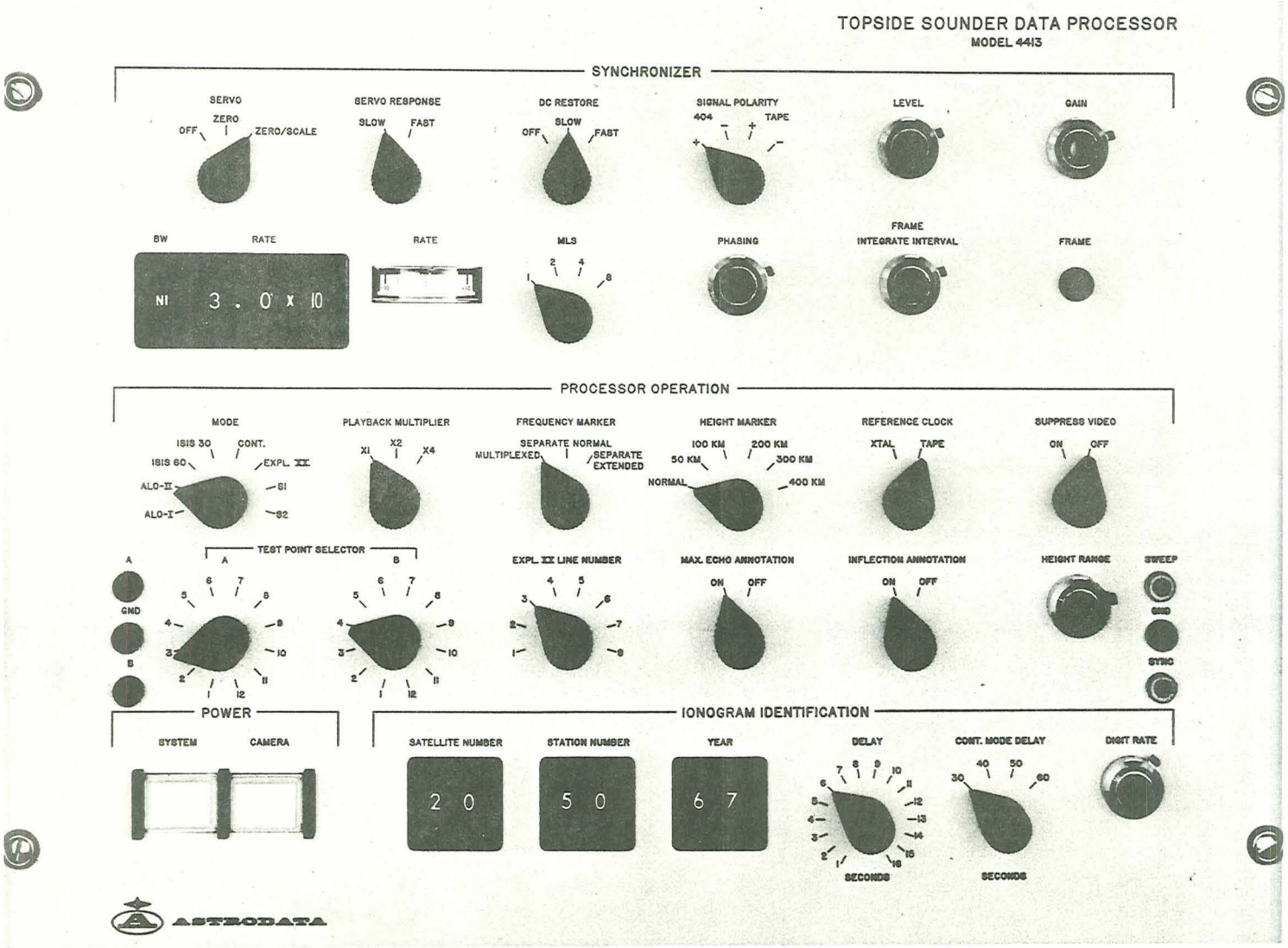
Present Topside Sounder data processing follows a so-called open-ended procedure. The telemetered video data on analog magnetic tape is converted to film ionograms using equipment of the type shown in the photographs in figure 7-1 and 7-2 following this page. The film ionogram is later projected on the screen of an optical data reader, and an operator manually scales $h_x'(f)$ data points along the X-trace, which are digitized and recorded along with calibration, universal time, and identification information. In most installations, the digital record generated by the film data reader is punched cards. However, punched paper tape and digital magnetic tape are also employed. Typical film digitizing equipment with digital magnetic tape output is shown in the photographs in figure 7-3 and 7-4. These computer-compatible records are then sent to a computation center as input data for N(h) computation. A flow diagram of this procedure is shown in figure 3-1.

With a computer-controlled semi-automatic data processing system, closed-loop processing of filmed ionograms now becomes feasible.



MODEL 4413 TOPSIDE SOUNDER DATA PROCESSOR

FIGURE 7–1



CONTROL PANEL TOPSIDE SOUNDER DATA PROCESSOR

FIGURE 7–2

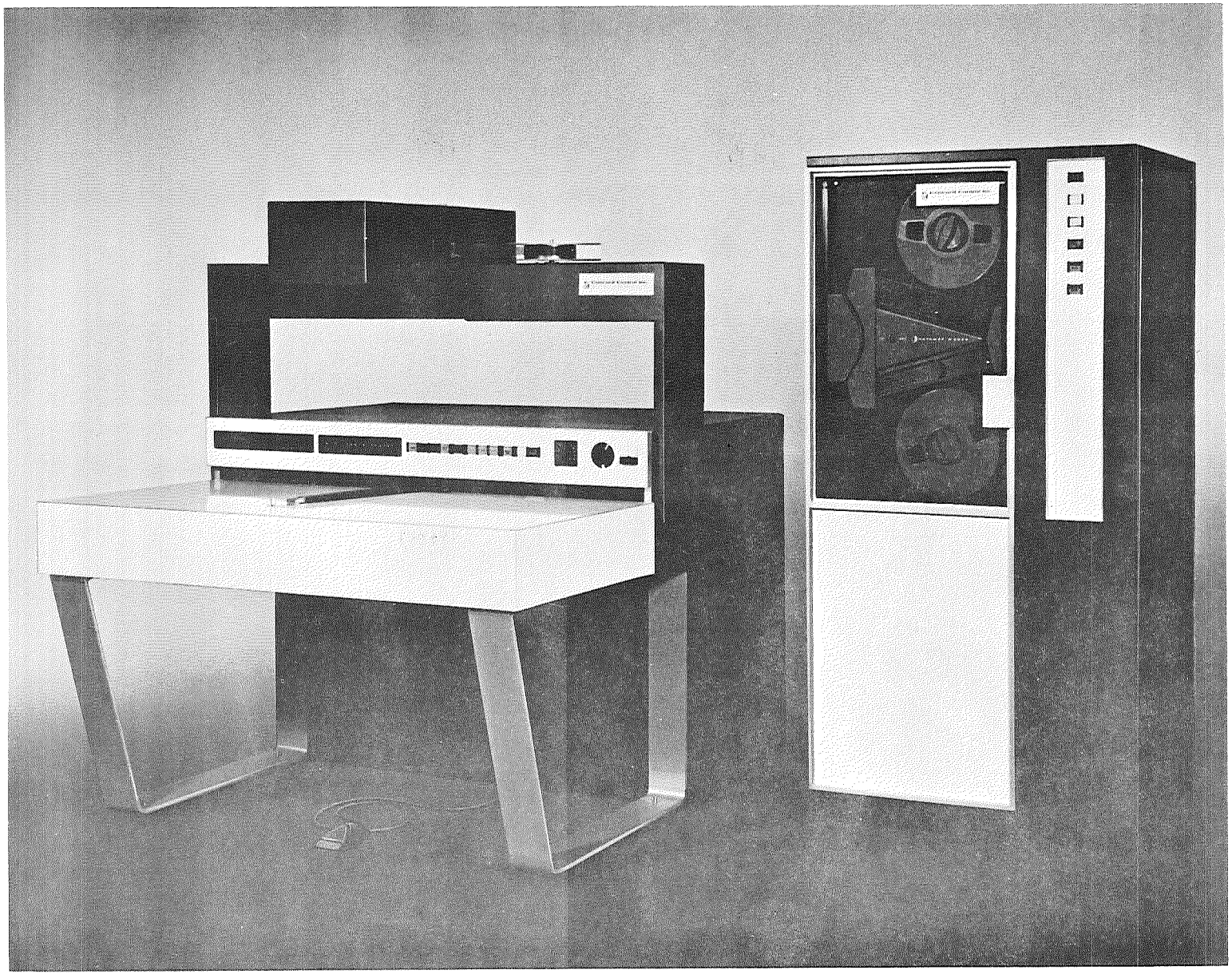


FIGURE 7–3 FILM DIGITIZING TABLE

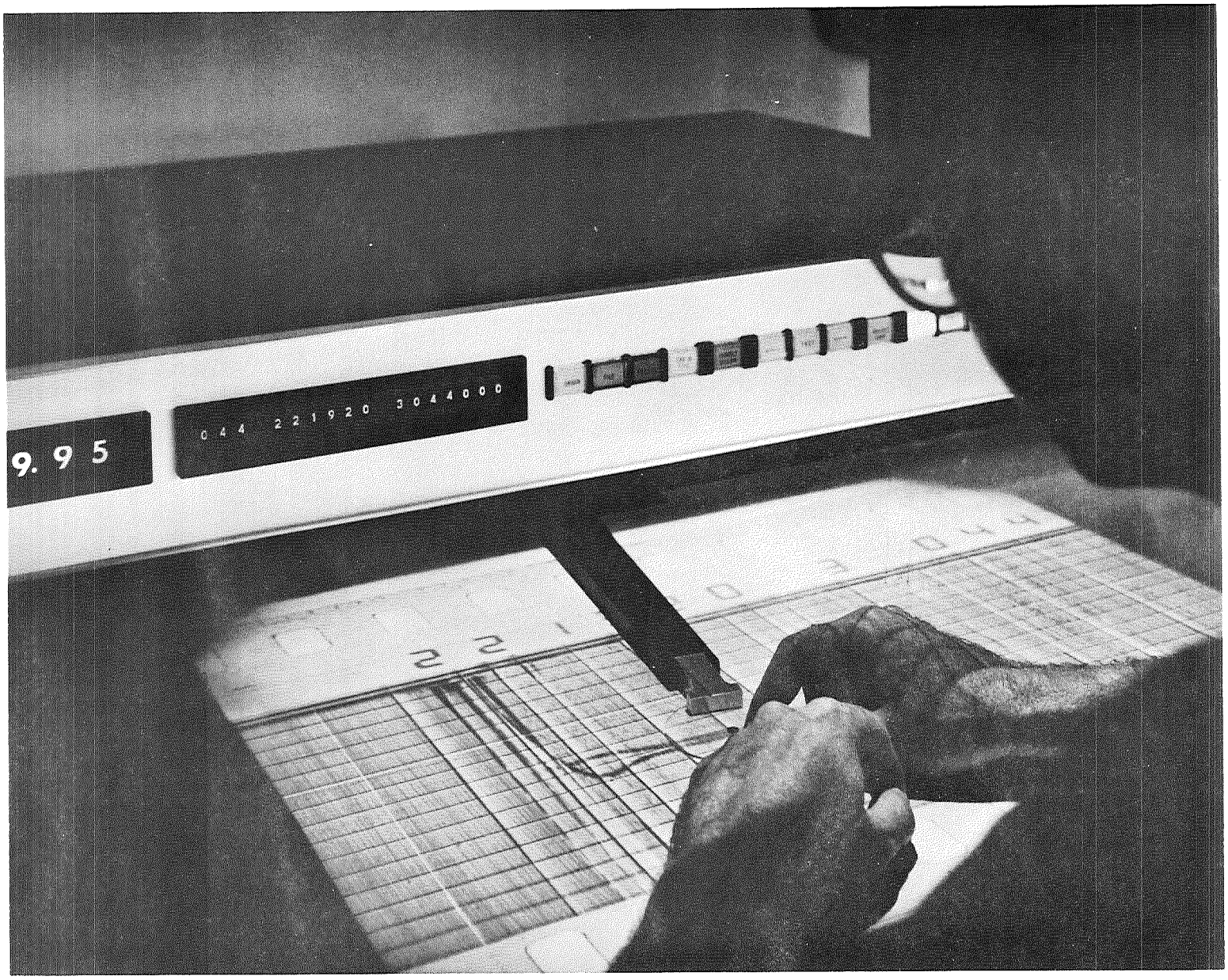


FIGURE 7–4 FILM DIGITIZER CONTROL PANEL

In this method, a computer-controlled CRT display would be conveniently located adjacent to the film digitizer. A sketch of a Film Digitizing Console of this type is shown in figure 7-5. Digital data from the optical data reader would be input directly into the computer and displayed on the CRT. A movable cursor spot on the CRT would continuously follow the cursor position of the data reader, which would enable the operator to relate information on the CRT with the projected film ionogram on the data reader.

7.1 CLOSED-LOOP PROCESSING

A typical closed-loop operating sequence might proceed as follows:

1. Select film and load on projector.

2. Project ionogram on data reader screen.

3. Align the reading head on the projected image so that the X axis is parallel to the range markers. This operation may be eliminated by taking data points at each end of a range marker and a frequency marker, and then have the computer perform coordinate rotation calculations on each subsequent data point as it is entered. Computation time for this correction would be negligibly small compared to the time required for an operator to select and input calibration and data points.

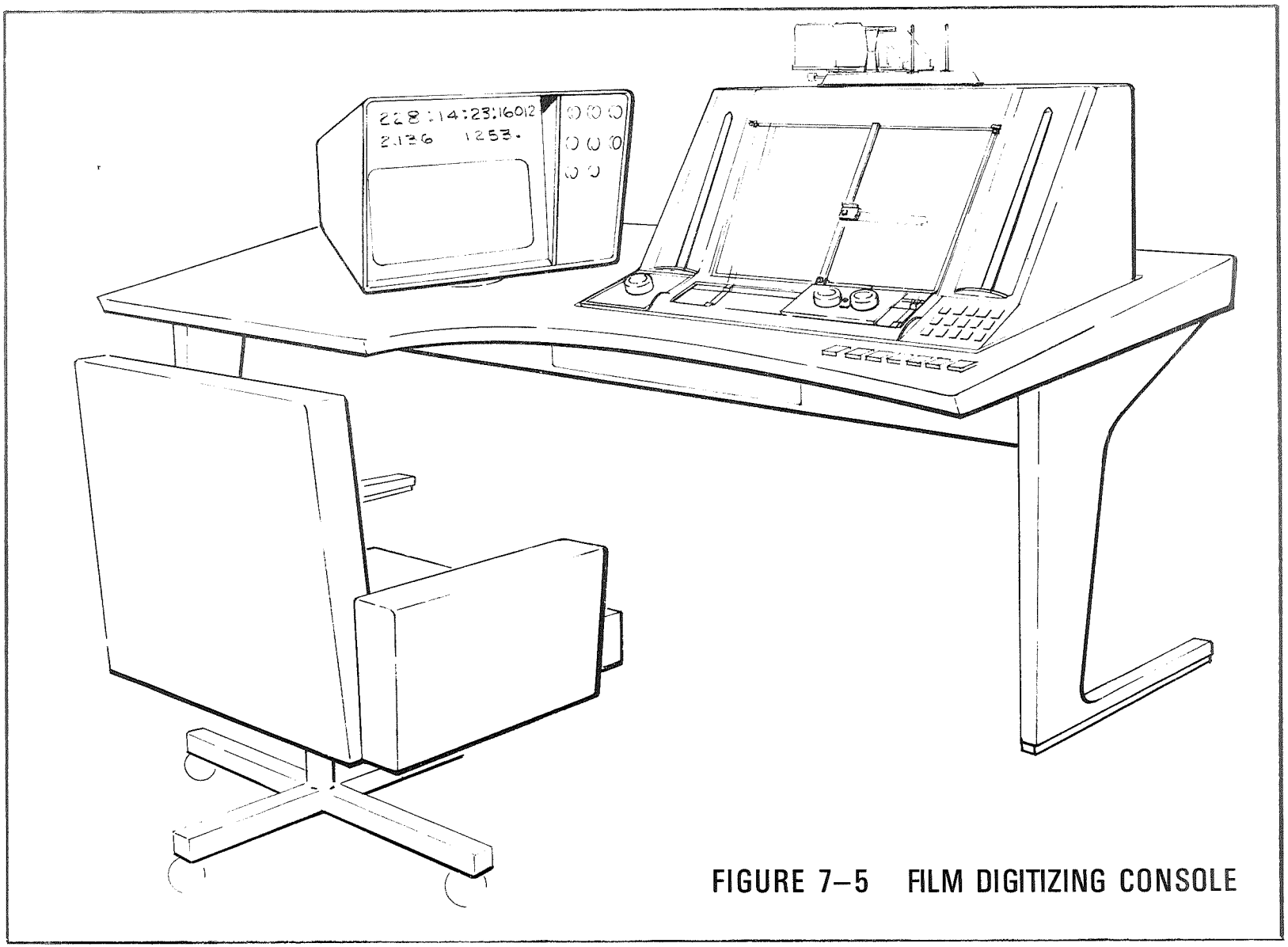


FIGURE 7–5 FILM DIGITIZING CONSOLE

4. Set the X-cursor on each of the frequency markers. The computer can now curve fit or linearly interpolate between the frequency markers so that any X-coordinate position is a known frequency. This frequency can be displayed to the operator on a numerical display so that subsequent data points at selected frequencies can be easily read into the computer. The frequency markers can be displayed on the CRT as the vertical lines of the coordinate system. The upper and lower frequency bounds--that portion of the ionogram to be displayed at this time on the CRT--can also be specified. If the CRT coordinate system is set up initially to represent a complete ionogram, the display scale factor can be changed at a later time so that only the frequency range of interest will fill the CRT screen.

5. Use the Y-cursor to digitize the position of the zero range marker and then the 1000 km, or 2000 km, or 4000 km range marker. The computer can now interpolate linearly between these points so that any Y-coordinate position is a known range. This range can be displayed to the operator on a numerical display so that the range of any subsequent data points are known as they are being read into the computer. The range markers can be displayed on the CRT as the horizontal lines of the coordinate system. The maximum range of the ionogram to be displayed on the CRT can be specified at this time.

If the CRT coordinate system is set up initially to represent the complete ionogram, the maximum range to be displayed on the CRT can be changed at a later time. Range marker lines at every 200 km can be displayed, with lines every 1000 km accentuated by increased width or brightness.

6. Set the X-cursor on the time dot represented by the time code at the bottom of the ionogram and enter the identification and time code information into the computer by the operator's keyboard.

7. Set the X-cursor on a time dot 10 seconds to the right of the reference time dot and enter into the computer. The computer can now interpolate linearly between the time dots so that any X-coordinate position is a known time as well as a known frequency (from 4). If desired, time can be displayed to the operator on a numerical display so that the time of subsequent data points can be observed by the operator.

8. The frequencies and maximum effective range of plasmas can be entered into the computer, and if the necessary ones are readable, a computer subroutine can give a predicted value of f_{xs} which is displayed as a bright dot on the CRT.

9. Interpret the X-trace of the ionogram by tracing over the projected image, with a finely pointed wax pencil, the interpretation that is to be scaled.

10. Place the X and Y cursors at f_{xs} on the drawn-in trace. The operator can compare the resulting position of the movable spot on the CRT with the computed position of f_{xs} (as given by 8). If the two points coincide, fine; if not, enter the cursor position as a separately identified choice for f_{xs}. Subsequent computation may determine whether the computed or scaled value of f_{xs} is the best one to use.

11. Move the X and Y cursors to select data points along the drawn-in X-trace. These data points will appear on the CRT in proper relation to the coordinate system as they are entered into the computer.

12. Interpret the usable portion of the O-trace (as in 9) and enter data points into the computer. The computer can curve-fit between data points to give a continuous curve for display on the CRT.

13. Compute $h_x'(f) \longrightarrow N_x(h) \longrightarrow \overline{h_o'(f)}$.

14. Computed data points from $\overline{h_o'(f)}$ can be compared on the CRT with scaled $h_o'(f)$ data (from 12). If, for many reasons, the X-trace, due to vertical propagation, is difficult to interpret, the $\overline{h_o'(f)}$ data points will likely not match the O-trace. The operator can now reinterpret the X-trace and go around the loop as many times as desired to get agreement between the O and X modes.

15. Compute output data and generate plots.

16. Repeat steps 3 to 15 for each succeeding ionogram.

On succeeding ionograms in the same pass, it may be possible to simplify step 4 on the basis that the frequency marker calibration will not change significantly for the duration of the pass. If two frequency markers are identified, one near the beginning and one near the end of the ionogram, the computer can perform a zero offset and gain adjustment on the new frequency marker inputs from the optical data reader so that the digital representation of these frequency markers will match the digital values of those frequency markers from the original frequency marker calibration data in computer memory. The frequency marker calibration data in computer memory should now fit the new ionogram without having had to read in all 22 frequency markers for each ionogram.

The addition of a computer-controlled CRT display to a film digitizing console makes it possible to process film ionograms using most of the techniques that have been described in Section III for processing Topside Sounder data directly from magnetic tape.

In addition to closed-loop operation, this includes mixed-mode processing, and extrapolation of data from previous ionograms for computation of a set of $\overline{h_x'(f)}$ data points as a reference for scaling the X-wave trace. This latter leads to implementation of scaling selection Rule 5, described in Section III, where the set of $h_x'(f)$ data points will result in laminations in the N(h) profile that are equally spaced in true height.

The most significant difference between processing film ionograms and real-time processing of data from analog magnetic tape is that with a film ionogram, there is no A-scan data per se. The amplitude profile of each A-scan line of the original data has been converted to a non-linear gray scale representation about a particular amplitude threshold. The original analog signal representing frequency, range and pulse amplitude, has become a variable density image in an X-Y coordinate system on film. It is more difficult to determine accurately the range, at a given frequency, for an $h_x'(f)$ data point from a film ionogram than from the original analog data on magnetic tape.

Nevertheless, a film ionogram is a compact low-cost method of storing a vast amount of Topside Sounder data. Large quantities of such data are now in this form. Closed-loop techniques may provide the only way in which many of the complex, high altitude ionograms can be processed. The extension of this technique to the processing of film ionograms may be of considerable help to the ionospheric research program particularly if the original analog magnetic tape is unavailable.

In a minimum type system configuration, it would be possible to time share the CRT display on the real-time ionogram operator's console with a film digitizing console directly coupled to the computer. A sketch of a combined console configuration is shown in figure 7-6 Time sharing in this configuration may likely consist of a separate shift operation, rather than a minute by minute time sharing, but it would provide the additional capability that has been described for closed-loop processing of film ionograms.

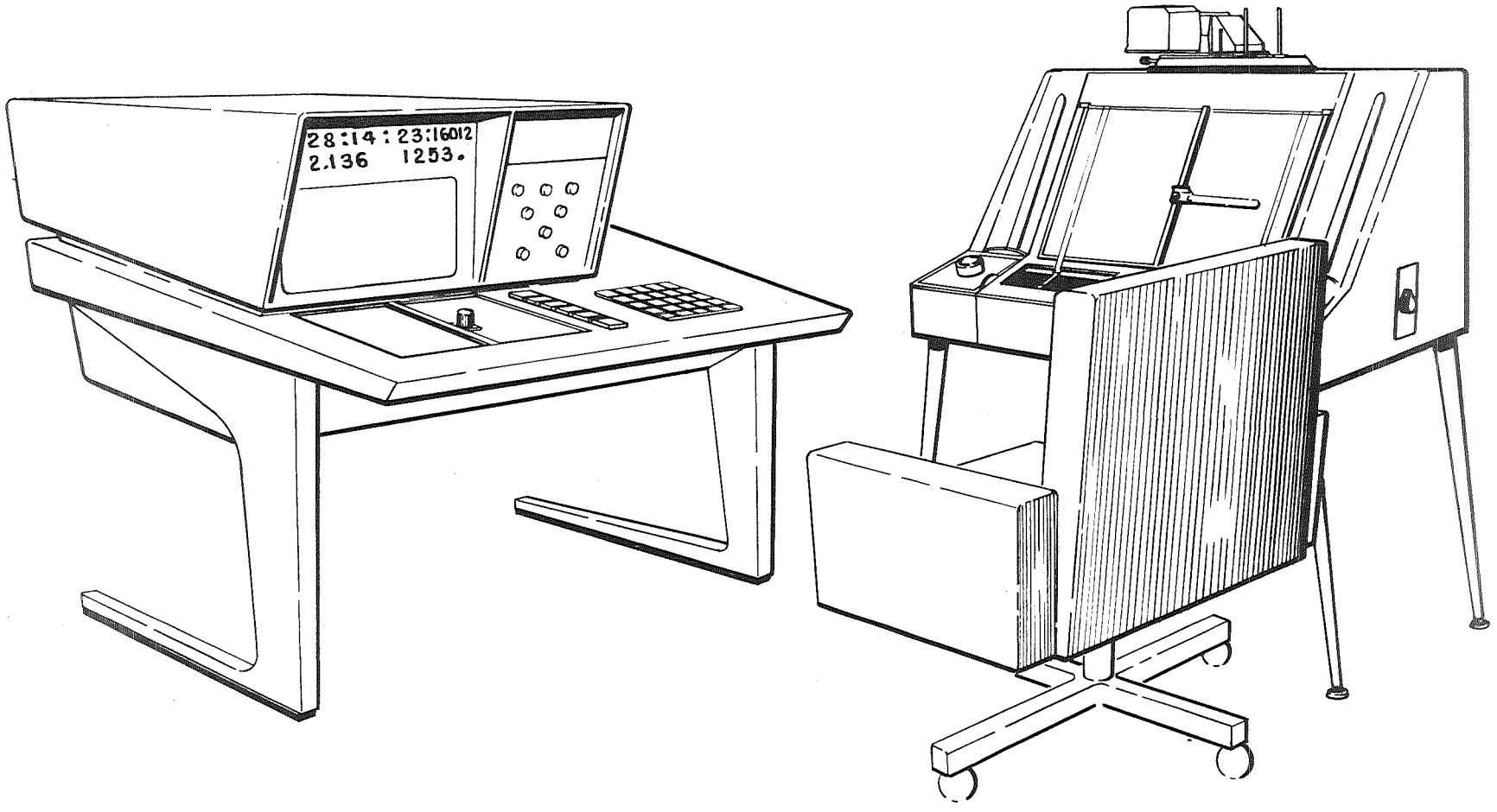


FIGURE 7–6 COMBINED REAL TIME IONOGRAM/FILM DIGITIZING CONSOLE

SECTION VIII

HARDWARE COST ESTIMATES

8.0 GENERAL

Most of the subsystems involved in the recommended system are existing proven designs. Aside from the gray scale converter and operator's consoles, there need be no development work. The principal development effort is concentrated in the real-time ionogram console/displays and the film digitizing console/displays, with their associated input/output couplers.

The absence of development work in the remainder of the system implies that no special circuit design or experimenting is required. The remaining items are either conventional digital computer peripherals or are units previously proved with Topside Sounder recorded signals. Thus, units are available commercially for all remaining elements of the system. Apart from the consoles, there should be little need for investment in non-recurring engineering costs for new designs; however, a specialized system such as this will involve non-recurring engineering dedicated to system integration.

A fixed-point, 16-bit, 900-nanosecond computer with 65,000 bytes of core memory and 2,000,000 bytes of disc memory, the suggested conventional peripherals and a representative set of mainframe options is typically priced from $250,000 to $280,000 ($7,500 per month lease). A floating-point machine of the

same scale with comparable peripherals would cost from $350,000 to $400,000 ($11,000 per month lease).

The subsystems involved in the analog signal reproduction and conversion of all data to the digital domain are expected to cost $150,000 to $180,000, including dual analog tape machines with tape search units and all necessary input/output peripheral controllers. The real-time ionogram operator's console with CRT display, programmable numerical displays and input keyboard, is estimated at $35,000, including input/output controllers and unpacking logic to accommodate the compressed ionogram gray scale data format. A film digitizing console with displays and keyboard is estimated at $25,000, (assuming a film data reader is supplied from present NASA inventory).

Price estimates include allowance for system integration, acceptance testing and installation.

The elapsed time for designing, manufacturing and acceptance testing the system should not exceed one year.

SIMULATION SOFTWARE

The simulation system has the capability of displaying 240 lines of video data, three lines of A-scan data and a storage capacity to hold the pulse range data from 240 lines of video data. The loader program accepts data from a punched paper tape containing 500 lines of video data, loading 240 lines of refresh data and pulse range information from the same 240 lines of video data into Pulse Store. A program option allows loading only odd numbered lines or even numbered lines. This provides a means for displaying a 16-second portion of the test ionogram, with only a 240 line display. Three consecutive lines of A-scan data can be loaded starting at any line number.

PREPROCESSING PHASE

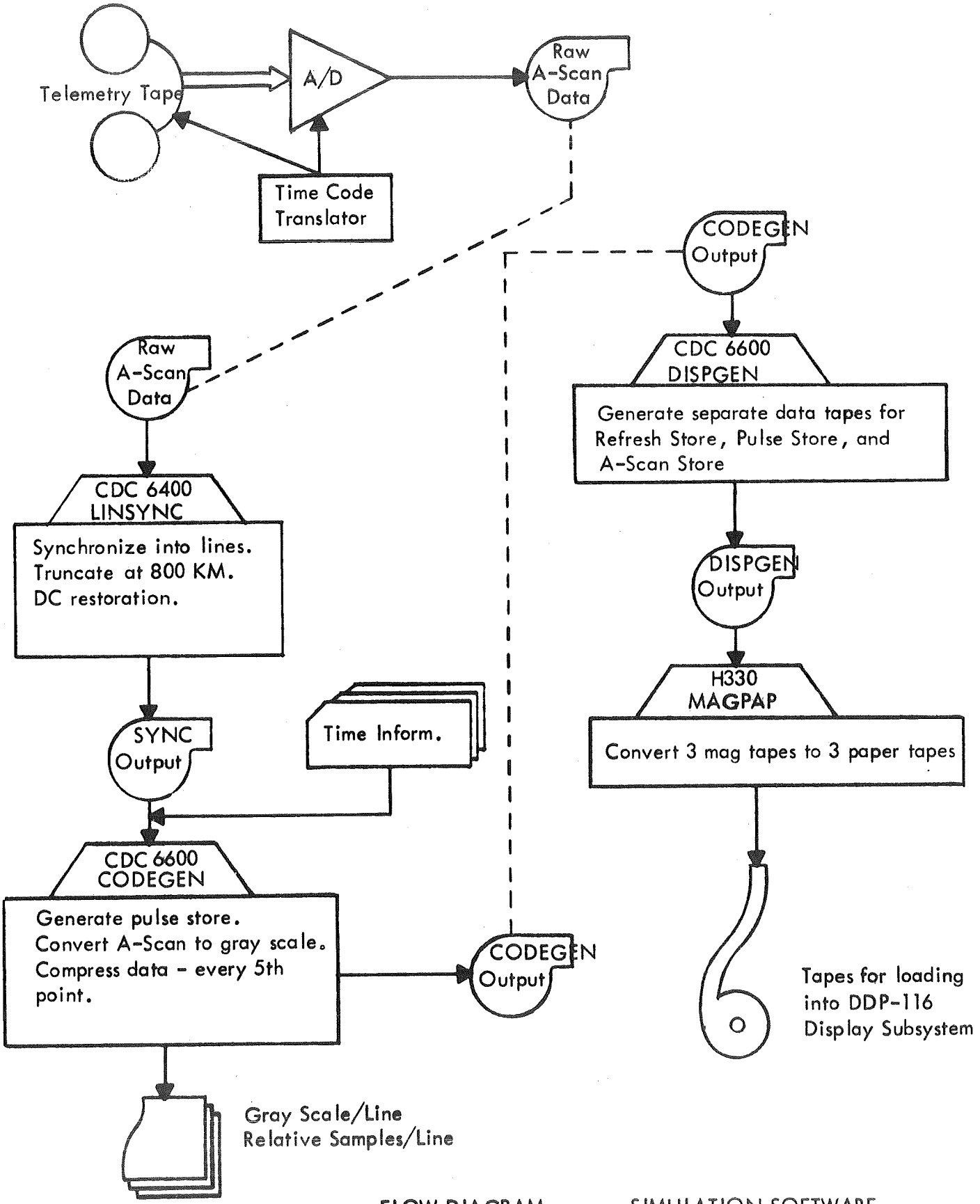
The software in this phase was written in FORTRAN IV programming language for the purpose of processing raw video data in digital form into a form suitable for input via punched paper tape into the project computer. This approach was considered adequate for the purposes of the study. The objective in building the simulator was to investigate the various aspects of a conversational mode type of operation between a human operator and a computer, with respect to the interpretation and scaling of traces from topside sounder ionograms. Preparation of data for use in the simulation study was independent of these study objectives. The original raw video data only had to be processed once.

In the proposed final system, the preprocessing phase will be an integral part of the overall software package, and the function of converting video data on an analog

magnetic tape to digital form, and then processing this raw digital data into the refresh store data format for ionogram picture display on the CRT will be an inherent capability of the proposed Topside Sounder Data Processor.

A flow diagram of the preprocessing phase of data preparation for the simulation study follows this page. In order to allow complete freedom of investigation without restraints that might otherwise be imposed, the video data for ionogram 20 50 66 049 1629 40 was digitized at an equivalent real-time sampling rate of 128,000 samples per second. The digital tape format consisted of a time word in days, hours, minutes, seconds, and milliseconds, followed by 29 data words. This frame is repeated 14 times to make up a logical record on a seven-track digital magnetic tape. The video data was digitized using an 11-bit analog-to-digital converter (ADC). The zero and gain settings on the wideband subcarrier discriminator were adjusted relative to the ADC so that 50 percent or more of the line synchronization pulse was driven below zero on the ADC, and full bandedge deviation in the direction of increasing pulse amplitude did not exceed 90 percent of the full scale range of the ADC.

Computer Program LINSYNC was written to read the raw digital data tape and to write a new tape that was suitable for input to the code generating program called CODEGEN.



FLOW DIAGRAM - - - SIMULATION SOFTWARE

PRE-PROCESSING PHASE

Program LINSYNC performed the following functions:

1. Read digital tape.

2. Searched for specified time words for start and stop.

3. Performed synchronization on line sync pulses.

4. Established mean value of scale and zero calibration pulses.

5. Restored dc component.

6. Established time zero with respect to line sync pulse.

7. Assembled a corrected data list for a line of data covering the range from 0 to 1200 km.

Program CODEGEN

Computer program CODEGEN operated on digital data from magnetic tape produced by the LINSYNC program, and produced a suitably formatted input magnetic tape for program DISPGEN. Program CODEGEN selected every fifth data sample which reduced the equivalent real time sampling rate to 25,600 samples per second. This gave data samples spaced 5.85 km apart. Program CODEGEN truncated the available data by selecting samples only between

100 km and 800 km. Data points for the ionogram being displayed were restricted to this range in order to minimize the size of the Refresh Store required.

Gray scale data was computed for eight levels with pulse amplitude boundaries linearly spaced on a logarithmic scale.

The program also performed the function of digital pulse detection in order to determine the range of the pulses on each line that were to be input to Pulse Store. The operation of the digital pulse detector gate that was implemented in the program is illustrated on the following page. The width of the gate is shown as 2B and the height of the gate, or amplitude, is shown as A. The detector gate is moved along the line of data until a point is reached where the midpoint of the gate is at the maximum value of all data elements within the detector gate. The amplitude test is then applied, which requires that the difference between the maximum and minimum values within the detector gate be equal to or greater than 75.*

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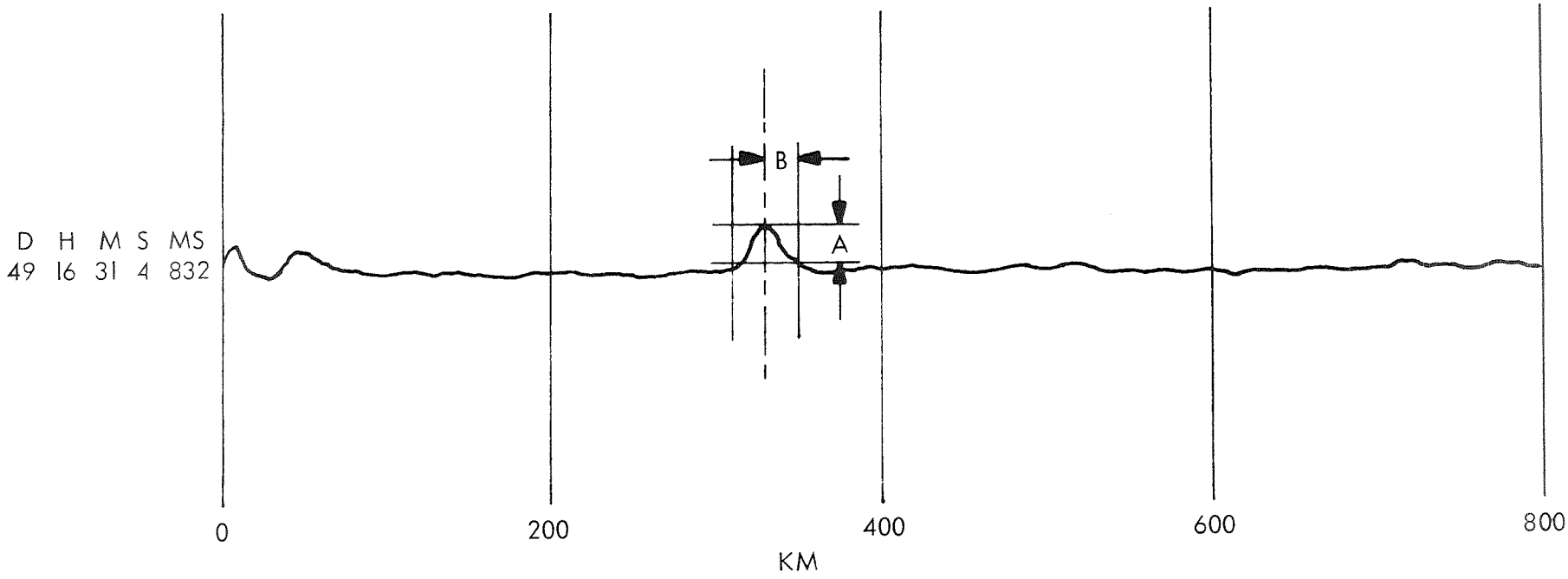
*See description of the amplitude scale page II-7.



DETECTOR GATE

The A-scan data was converted from the original digitized amplitude levels by dividing by 12 in order to convert the numerical scale from 1000 to a nominal 80 to make the maximum A-scan deflection approximately 10 mm with an incremental resolution of 1/8 mm.

The A-scan, gray scale conversion and pulse detection operations were performed on 500 lines of video data between specified time boundaries. A second run of program CODEGEN was made in which data for a four-level gray scale was computed and listed in order to compare the amplitude distribution between 4-level and 8-level gray scale codes.

Program CODEGEN output digital magnetic tape consisted of the following:

1500 Records - 3/Records/Line - 500 Lines

Record 1 - Gray scale data - 120 words

Record 2 - A-scan data - 137 words

Record 3 - Track store data - variable word count with the last word containing the count

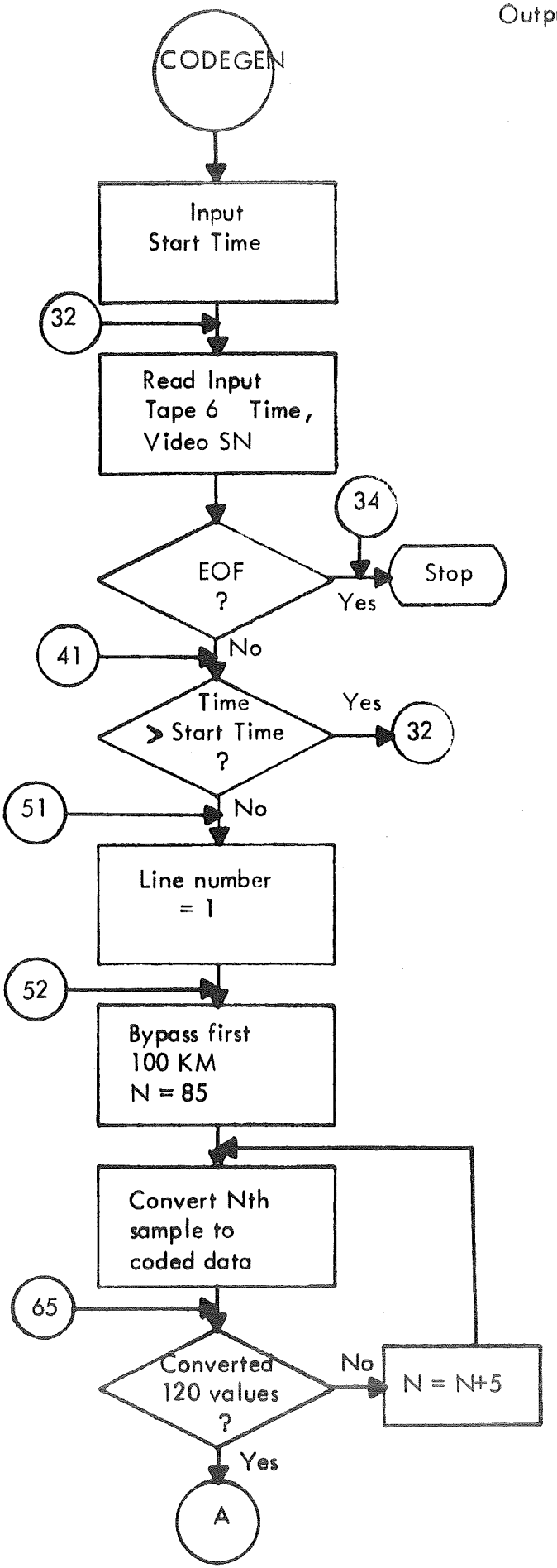
A flow diagram of program CODEGEN follows this page.

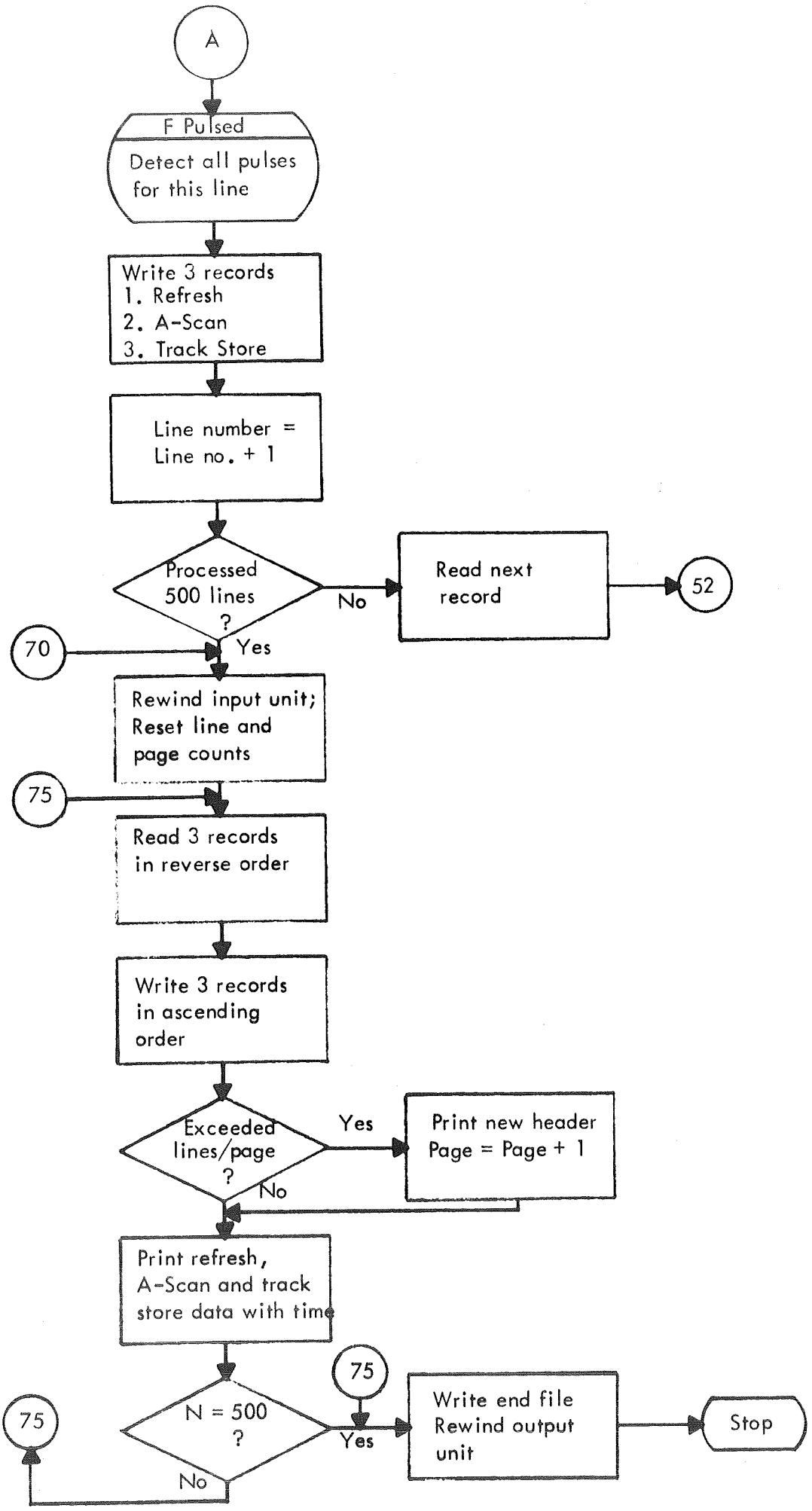
FORTRAN - CODEGEN

Input - Reverse LINSYNC tape

Output - Forward coded A-Scan pulse data

500 lines - 3 rec/line




A
F Pulsed
Detect all pulses for this line
Write 3 records
1. Refresh
2. A-Scan
3. Track Store
Line number = Line no. + 1
Processed 500 lines ?
No
Read next record
52
Yes
70
Rewind input unit; Reset line and page counts
75
Read 3 records in reverse order
Write 3 records in ascending order
Exceeded lines/page ?
Yes
Print new header Page = Page + 1
No
Print refresh, A-Scan and track store data with time
75
N = 500 ?
Yes
Write end file Rewind output unit
Stop
75
No

Program DISPGEN

Program DISPGEN converted the gray scale data values from the CODEGEN tape into the compressed data format for the Refresh Store. The detailed structure of the compressed data words is shown following page II-7. The data in DISPGEN was bounded by a start code; line number and stop code and placed on magnetic tape in a convenient format for conversion to punched paper tape. Both A-scan and Pulse Store data were identically blocked and then output on their respective magnetic tapes.

Refresh data was formatted to contain a starting X-word, a series of G-words, and Y incremental or direct skip words. The last word in each line was a G-word with the last GS-word having a gray scale level of 000. Y skip words were generated when at least five successive characters were the same as the last character in a group of five GS-words. The starting X-word contained the address of the first non-zero data, which was never less than 17 counts (100 km). The program processed the complete 500 lines of data from the CODEGEN output tape.

INPUT/OUTPUT

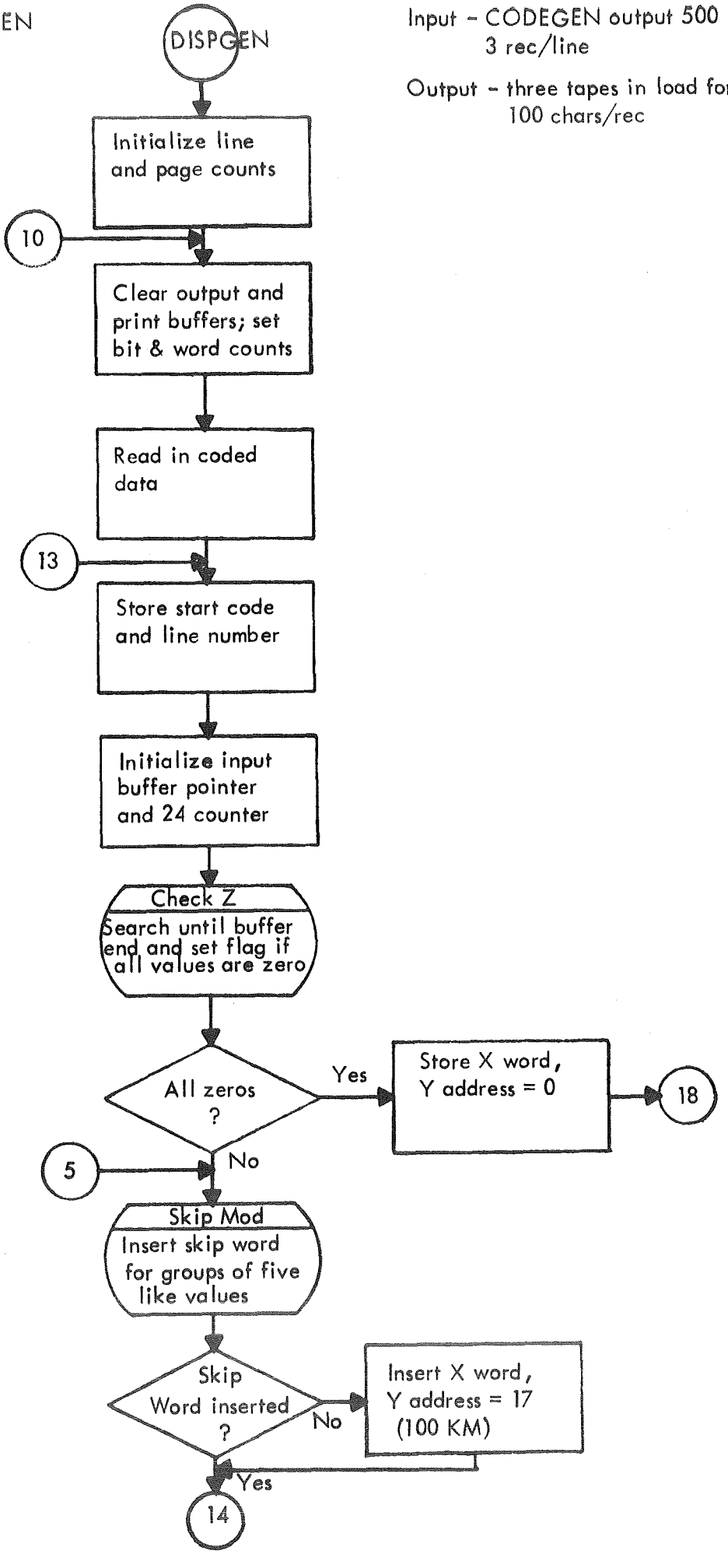
Tape 6 - CODEGEN output tape
Tape 7 - Refresh Formatted data - 100 characters/record
Tape 8 - A-Scan data - 100 characters/record, 5 records/line
from lines 285 to 316
Tape 0 - Track Store data - 100 characters/record

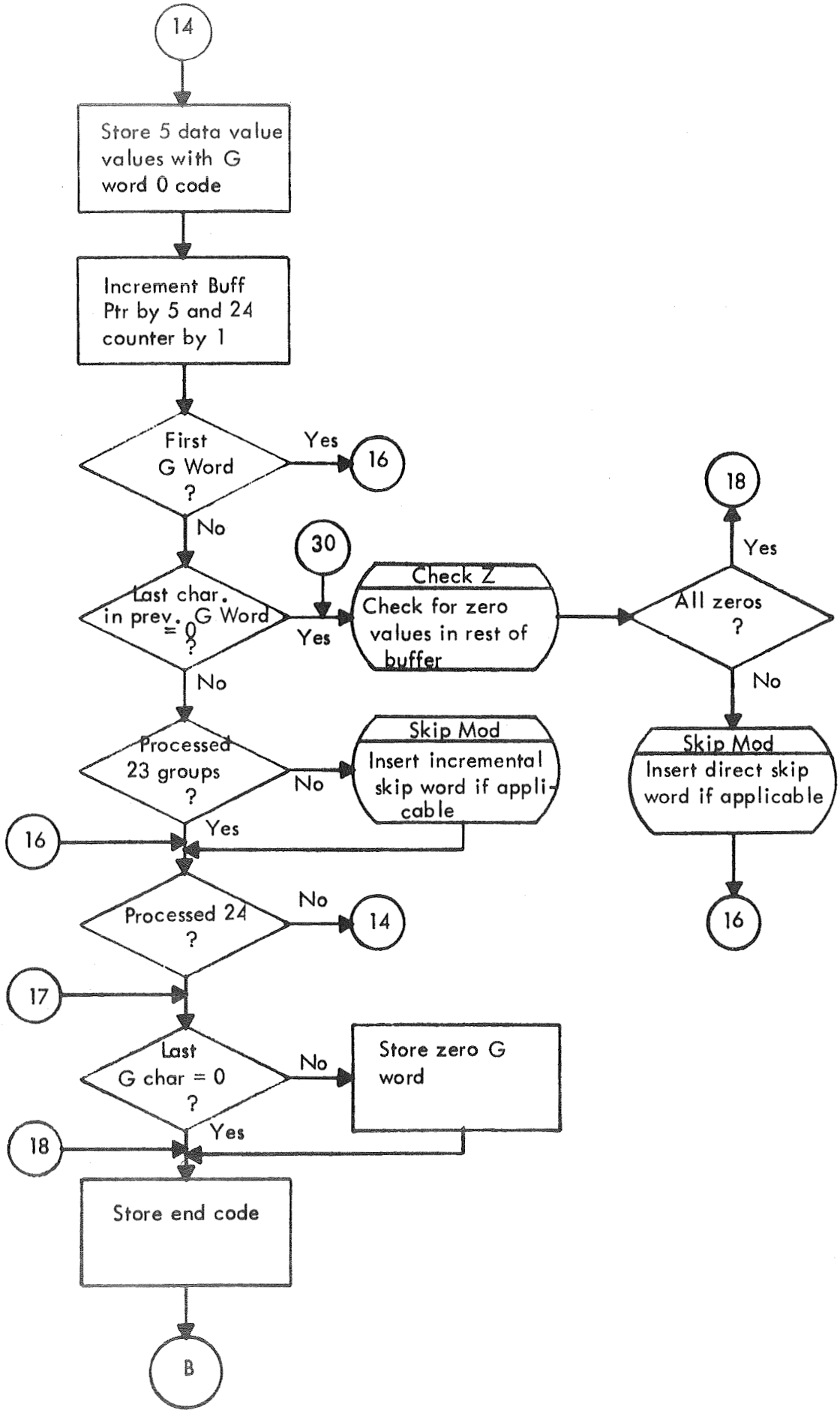
A flow diagram of Program DISPGEN follows this page.

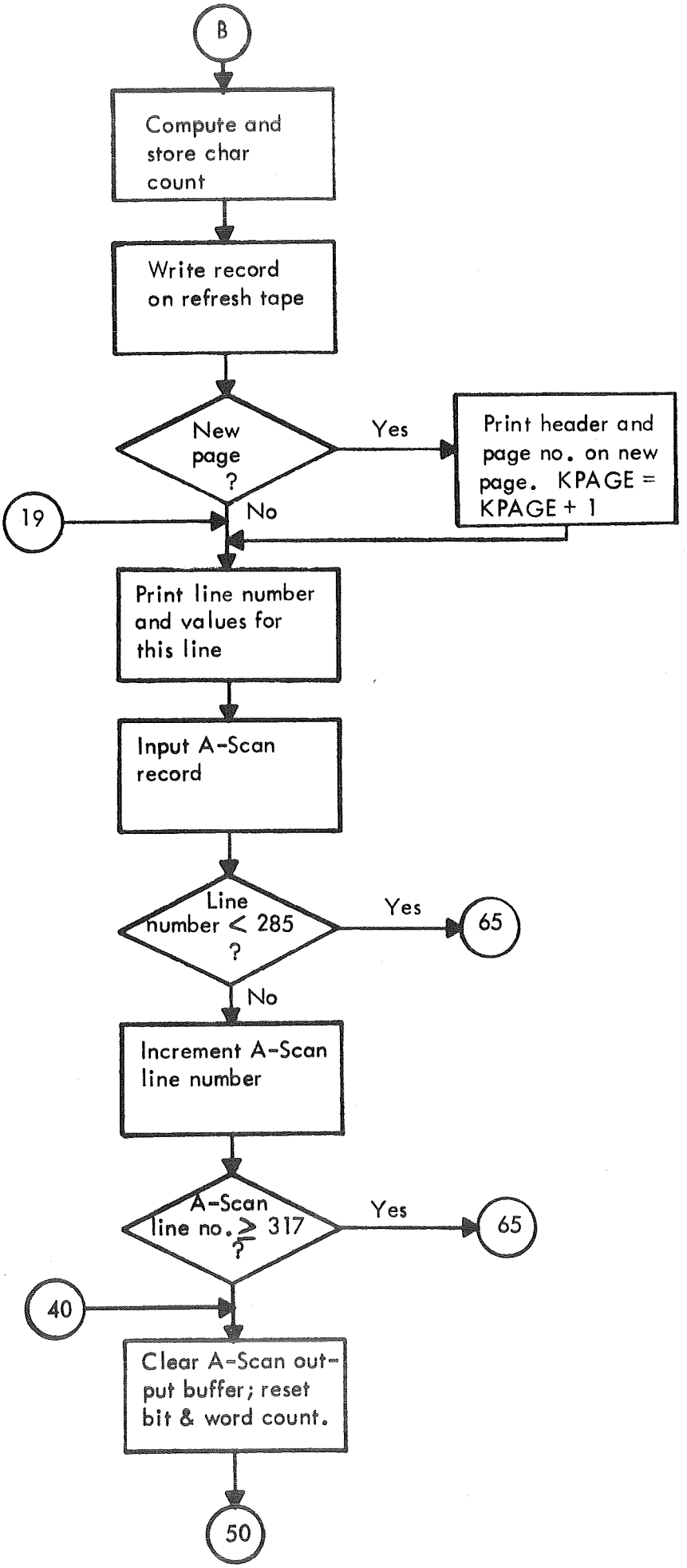
FORTRAN - DISPGEN

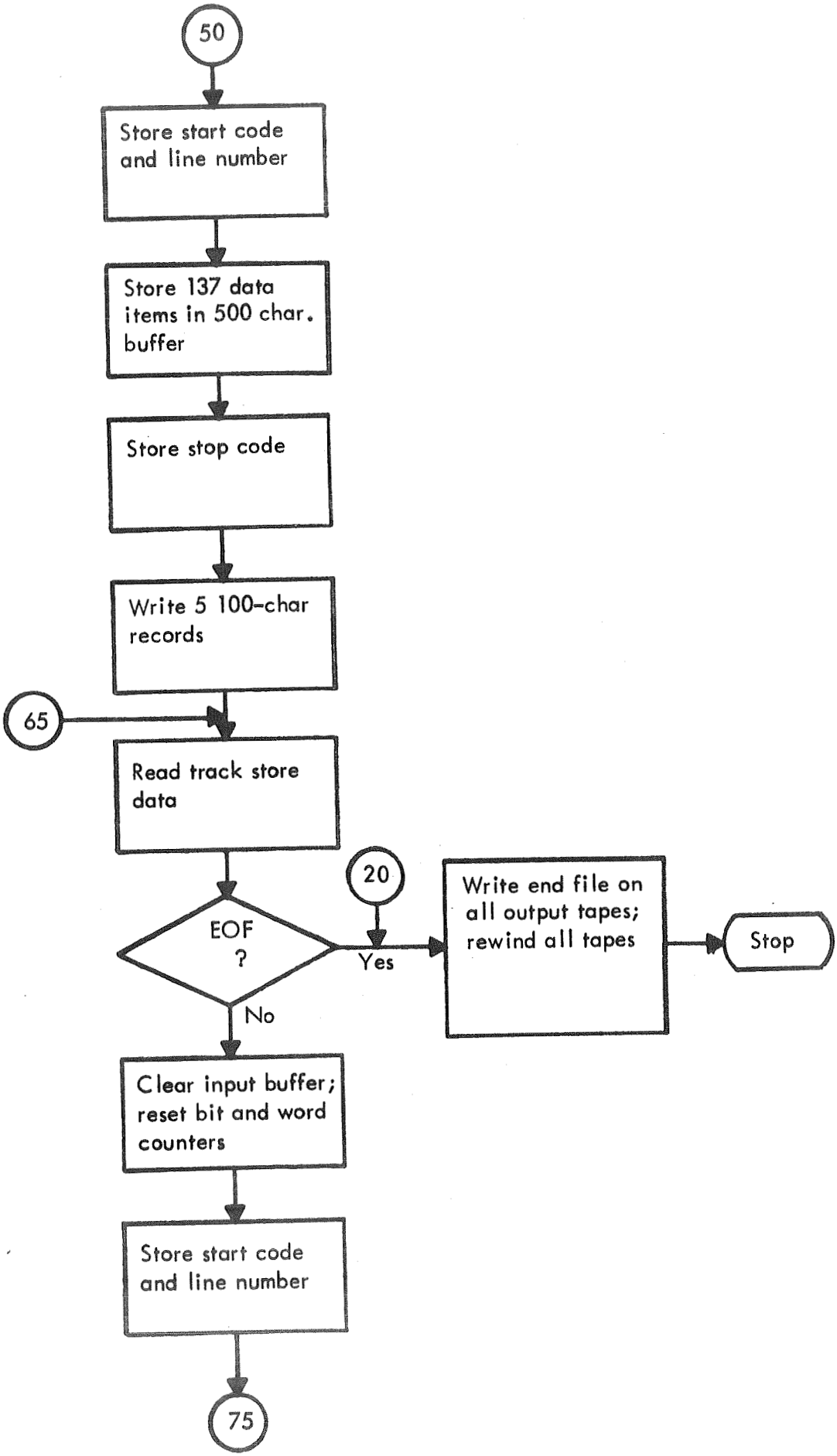
Input - CODEGEN output 500 lines
3 rec/line

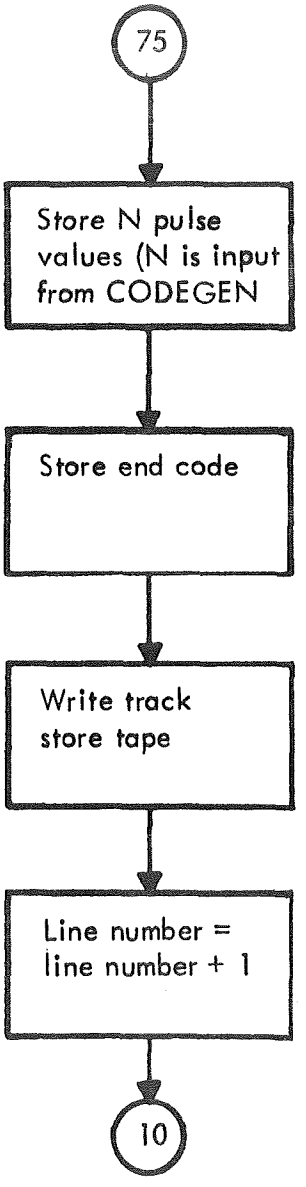
Output - three tapes in load format
100 chars/rec



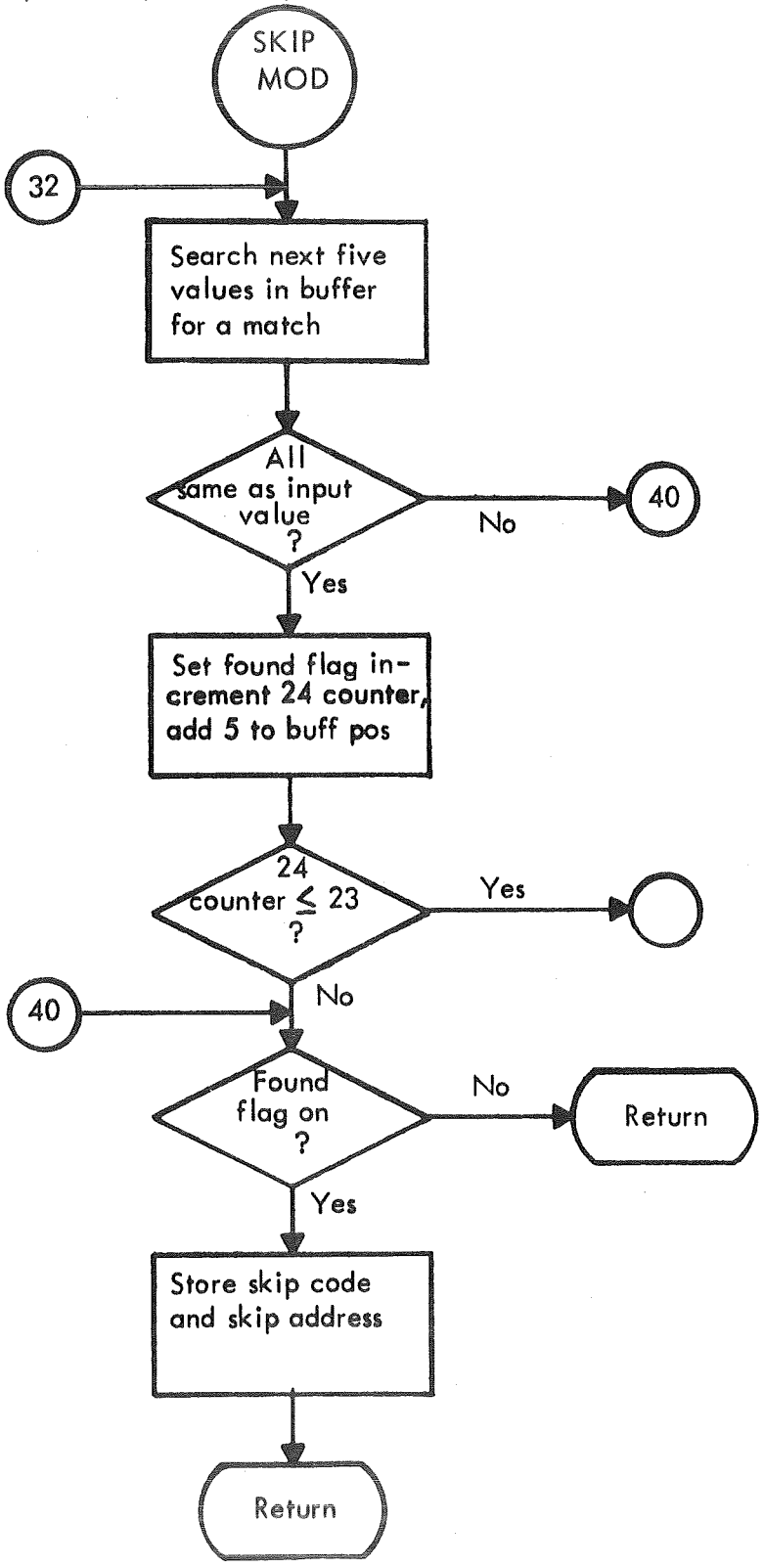

14
Store 5 data value values with G word 0 code
Increment Buff Ptr by 5 and 24 counter by 1
First G Word ?
Yes
16
No
30
Last char. in prev. G Word = 0 ?
Yes
Check Z
Check for zero values in rest of buffer
All zeros ?
Yes
18
No
Skip Mod
Insert direct skip word if applicable
16
No
Skip Mod
Insert incremental skip word if applicable
Processed 23 groups ?
No
Yes
16
Processed 24 ?
No
14
17
Last G char = 0 ?
No
Store zero G word
Yes
18
Store end code
B


B
Compute and store char count
Write record on refresh tape
New page ?
Yes
Print header and page no. on new page. KPAGE = KPAGE + 1
19
No
Print line number and values for this line
Input A-Scan record
Line number < 285 ?
Yes
65
No
Increment A-Scan line number
A-Scan line no. ≥ 317 ?
Yes
65
40
Clear A-Scan output buffer; reset bit & word count.
50


50
Store start code and line number
Store 137 data items in 500 char. buffer
Store stop code
Write 5 100-char records
65
Read track store data
20
EOF ?
Yes
Write end file on all output tapes; rewind all tapes
Stop
No
Clear input buffer; reset bit and word counters
Store start code and line number
75

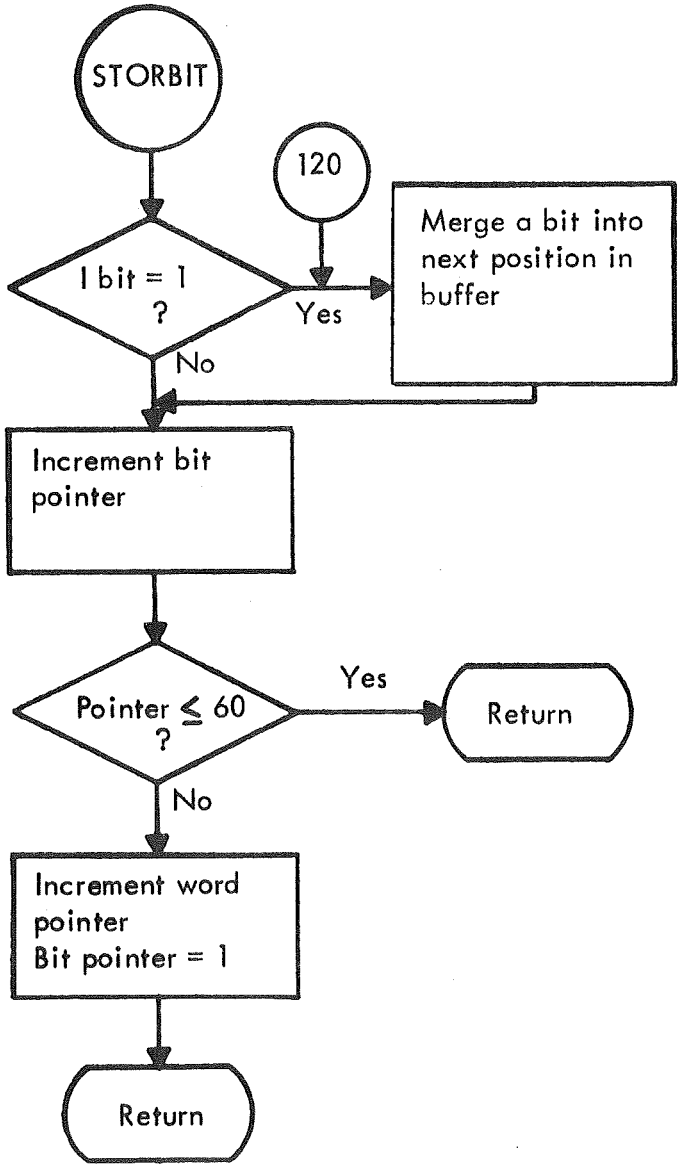

75
Store N pulse values (N is input from CODEGEN
Store end code
Write track store tape
Line number = line number + 1
10

SUBROUTINE - Input - Char. value, skip code
Output - Skip word output, 24 counter incremented

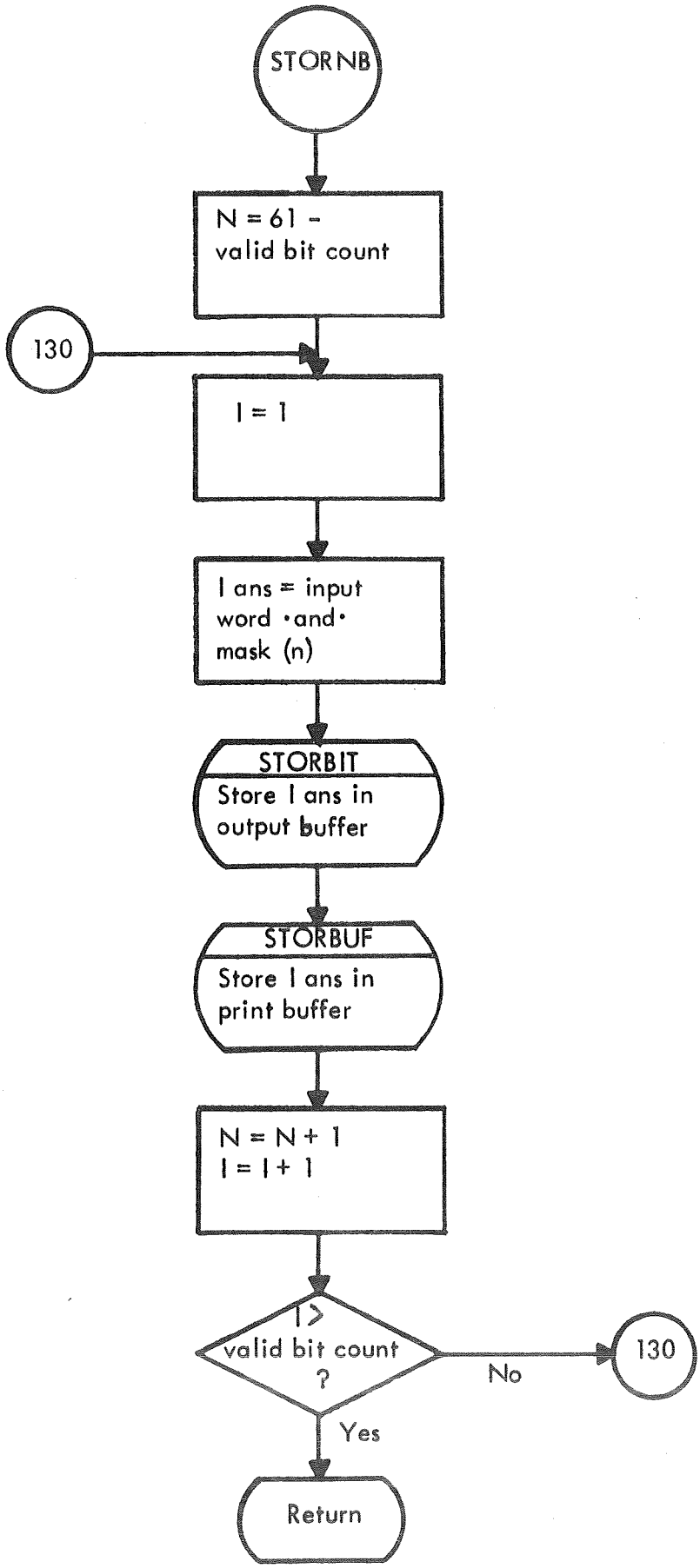


SUB ROUTINE - Input - 1 bit = 0, 1

Output - stored bit in next buffer position

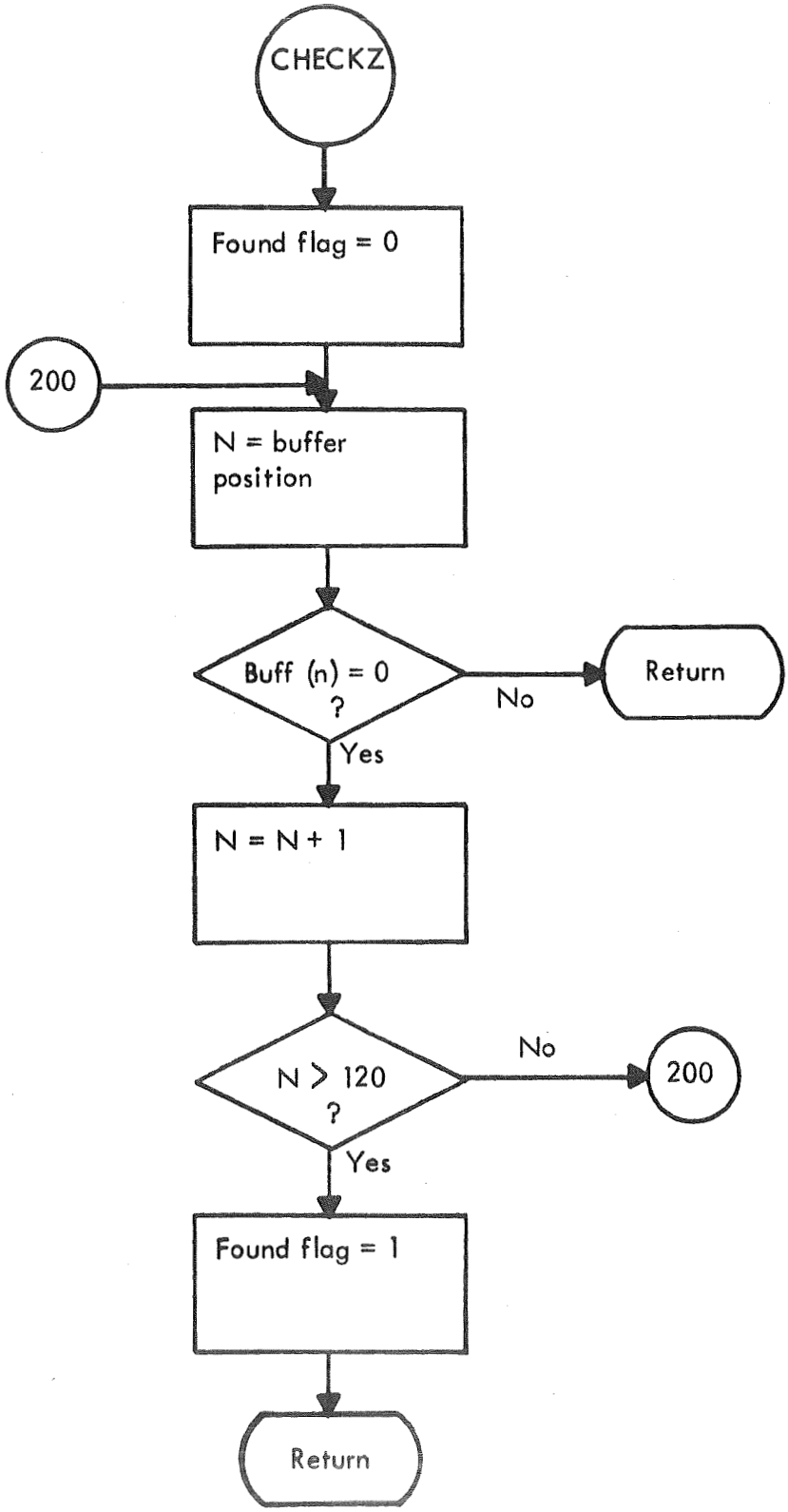


SUBROUTINE - Input - Input word, valid bit count right justified
Output - stored value in output buffer



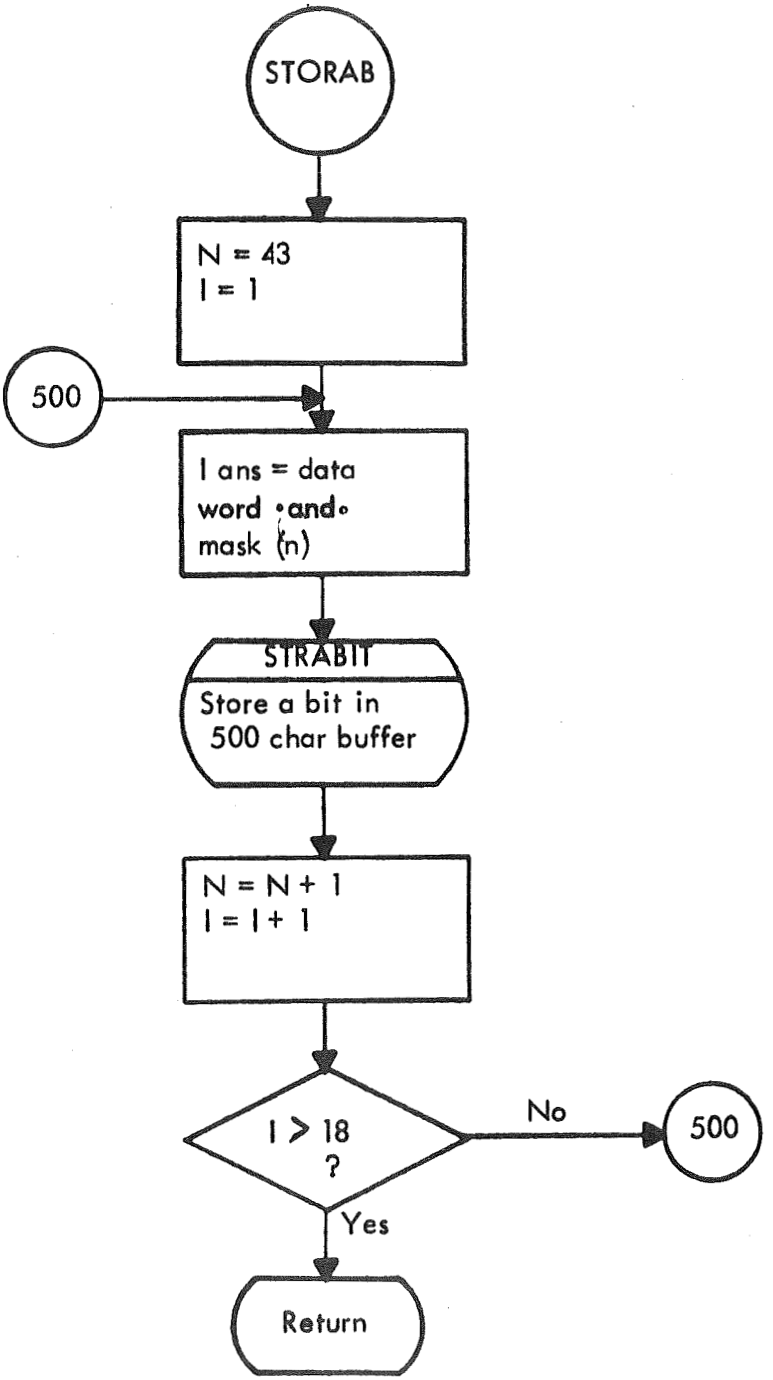
SUBROUTINE - Input - current buffer position

Output - flag = 1 if all succeeding values = 0

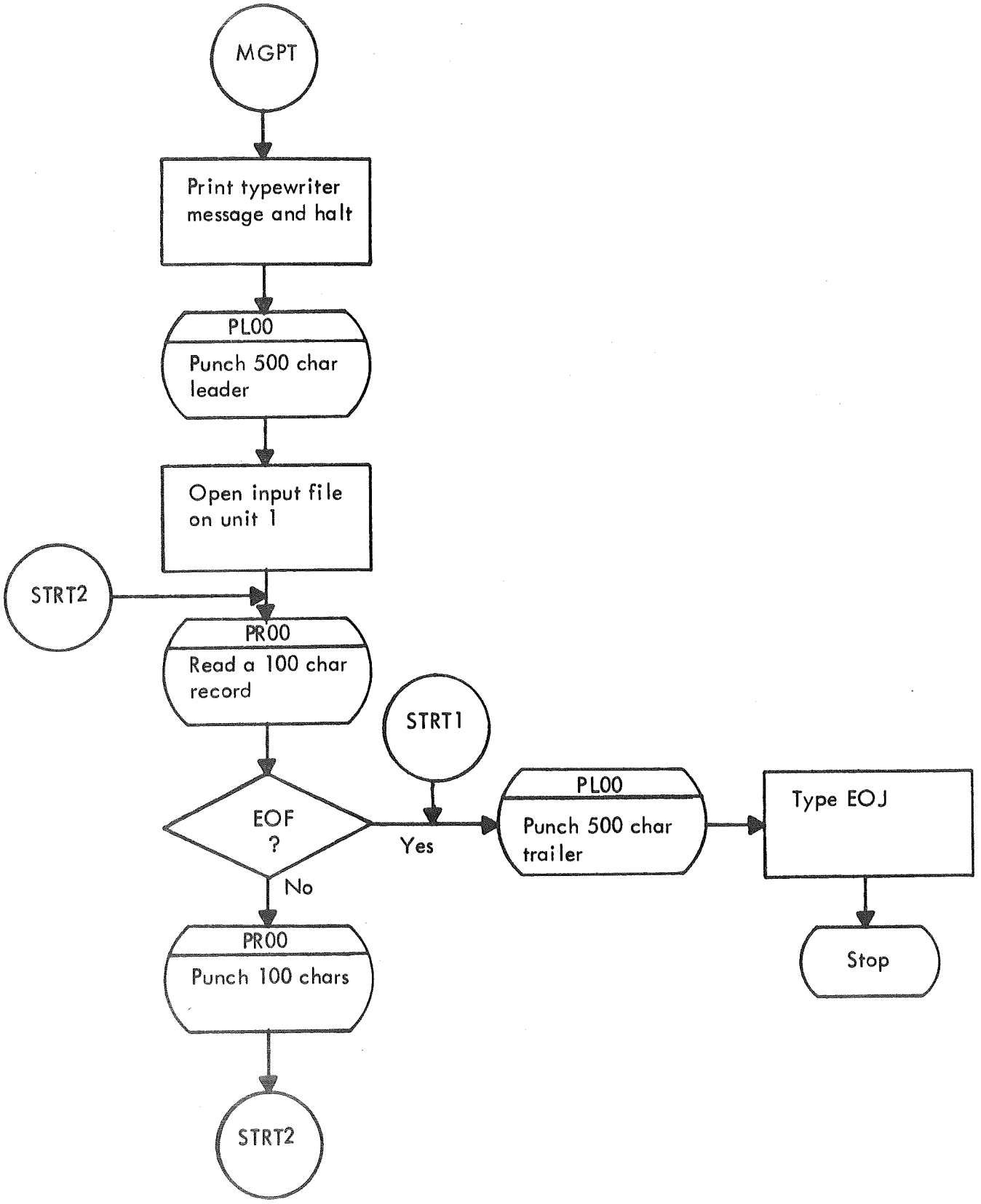


SUBROUTINE - Input - 18 bit data word

Output - word inserted in output buffer



HUGHES - MAG TAPE TO PAPER TAPE



Magnetic Tape to Paper Tape

Program MAGPAP was written to be run on a Hughes 330B Digital Computer. This program read a binary record of 100 characters and punched it on paper tape. There was no conversion, just a one for one character transfer from the input magnetic tape to the output paper tape punch.

A flow diagram of Program MAGPAP follows this page.

PHASE TWO SOFTWARE

The Loader and Display programs were written in assembly language and compiled on an IBM 1440 Digital Computer using a cross assembler program. The output of this program was a perforated paper tape which was entered into the simulation computer using the high-speed paper tape reader. The Loader program controlled the input of Refresh, Pulse Store, and A-scan data that were preprocessed on punched paper tape. The Display program controlled the various displays, and accepted operator control and data input information from the program control switches and the cursor spot control system.

The Loader program was constructed in such a way that it did not have to remain in memory while the simulation display was in operation.

The Display program was a key portion of the study program and was written and then modified several times in order to try out various ideas and techniques for various types of displays.

Loader Program

The Loader program used the high-speed paper tape reader to input display buffer information and set up addresses and counts for the Display program. The input paper tape was formatted identically for the Refresh Store, Pulse Store and A-scan data. A record corresponding to one line of data contained a start code (177776), a line number, a block of data, and a stop code (177775). Refresh and Track Store data were grouped into 100-character blocks with a variable number of blank characters appearing after the stop code. A-scan data was grouped into 500-character blocks.

When the data loading operation is performed, the paper tape is read until a start code is encountered. The line number is then read and compared against the input starting line number. As soon as the starting line number is found, the data is loaded into the appropriate buffer until the stop code is detected. Loading is completed when 240 lines of either Pulse Store or refresh data, or three lines of A-scan data have been loaded. The tape has even parity and a parity check is made on each character. A message is printed on the typewriter if an error is detected.

The following loading options are provided for entering refresh data into the two refresh buffers, BUFA and BUFB.

A. Load odd-numbered lines in BUFA and even-numbered lines in BUFB.

B. Load the first 120 lines of refresh data in BUFA and the remaining 120 lines in BUFB.

C. Load the first 120 odd (even) numbered lines of refresh data in BUFA and the remaining 120 odd (even) numbered lines in BUFB.

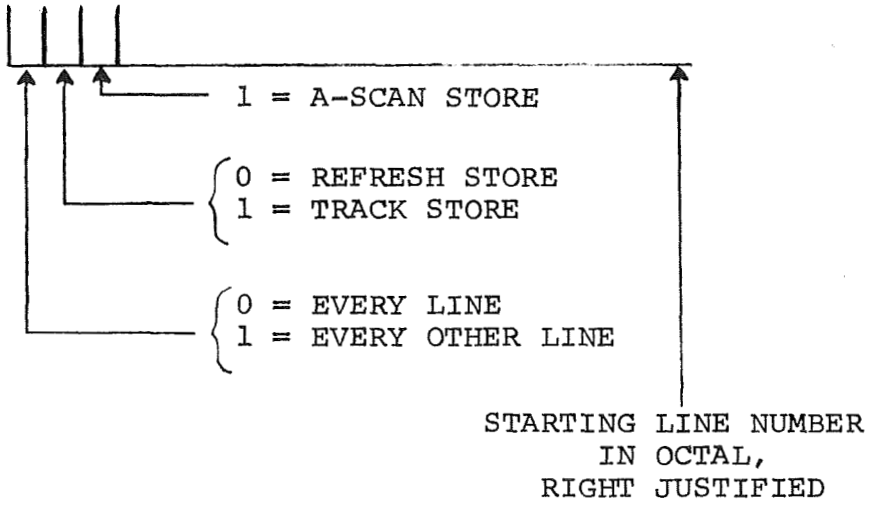
In the Display program the two buffers in refresh store are displayed in alternate sequence. Option A provides a means for an interlaced scanning display by displaying first the odd-numbered lines of the picture followed by the even-numbered lines of the picture. When the refresh data is loaded under option B, the ionogram picture display is not interlaced. The first half of the picture and the second half are displayed in consecutive order, which gives the appearance of one continuous picture raster. When refresh data is loaded under option C, a 16-second portion of the ionogram is displayed. Since the display is limited to 240 lines, the picture is made up of only odd-numbered lines if the starting point line number is an odd number, or it can be made up as a display of only the even-numbered lines if the loader starting line number is an even number.

A-scan data is combined with the X-word code (170000) and arranged for display starting on line 243 (to the right of the ionogram picture).

When Pulse Store data is loaded, an address table is constructed for locating pulses on a given line in the Pulse Store. If a situation occurs where there are no

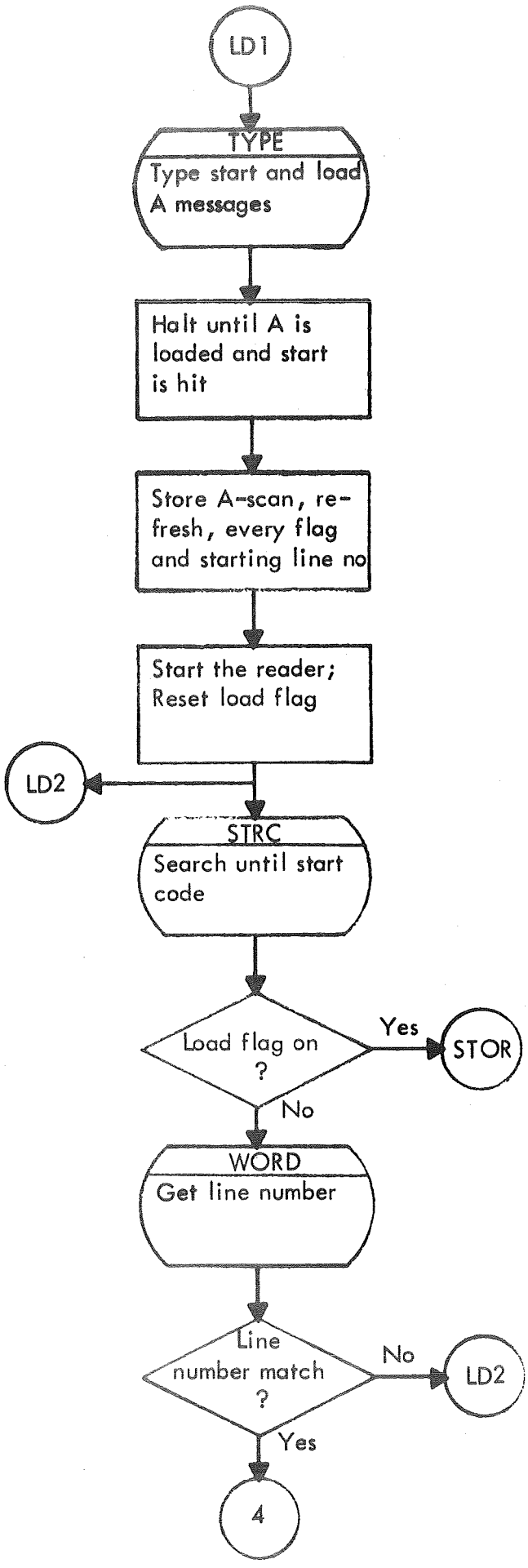
pulses on a line, two consecutive pointers in the Pulse Store address table will be identical.

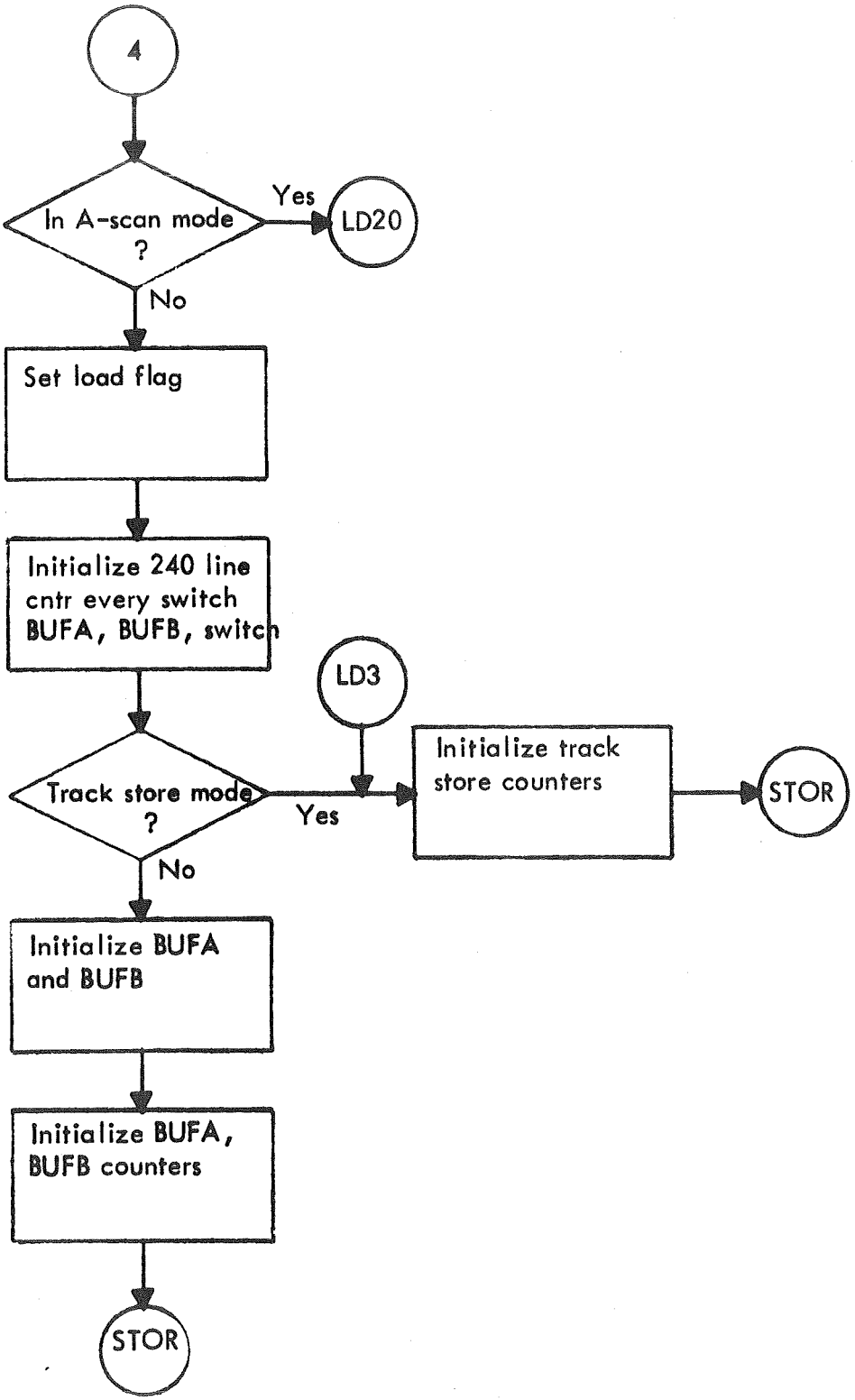
The loader operating procedure is initiated by closing program control switch LOAD while the display program is running. The paper tape containing the desired display data is loaded on the high-speed paper tape reader. The typewriter will print out instructions to start the reader and load the A register with the mode and starting line number. The computer A register word format for loader input is as follows:

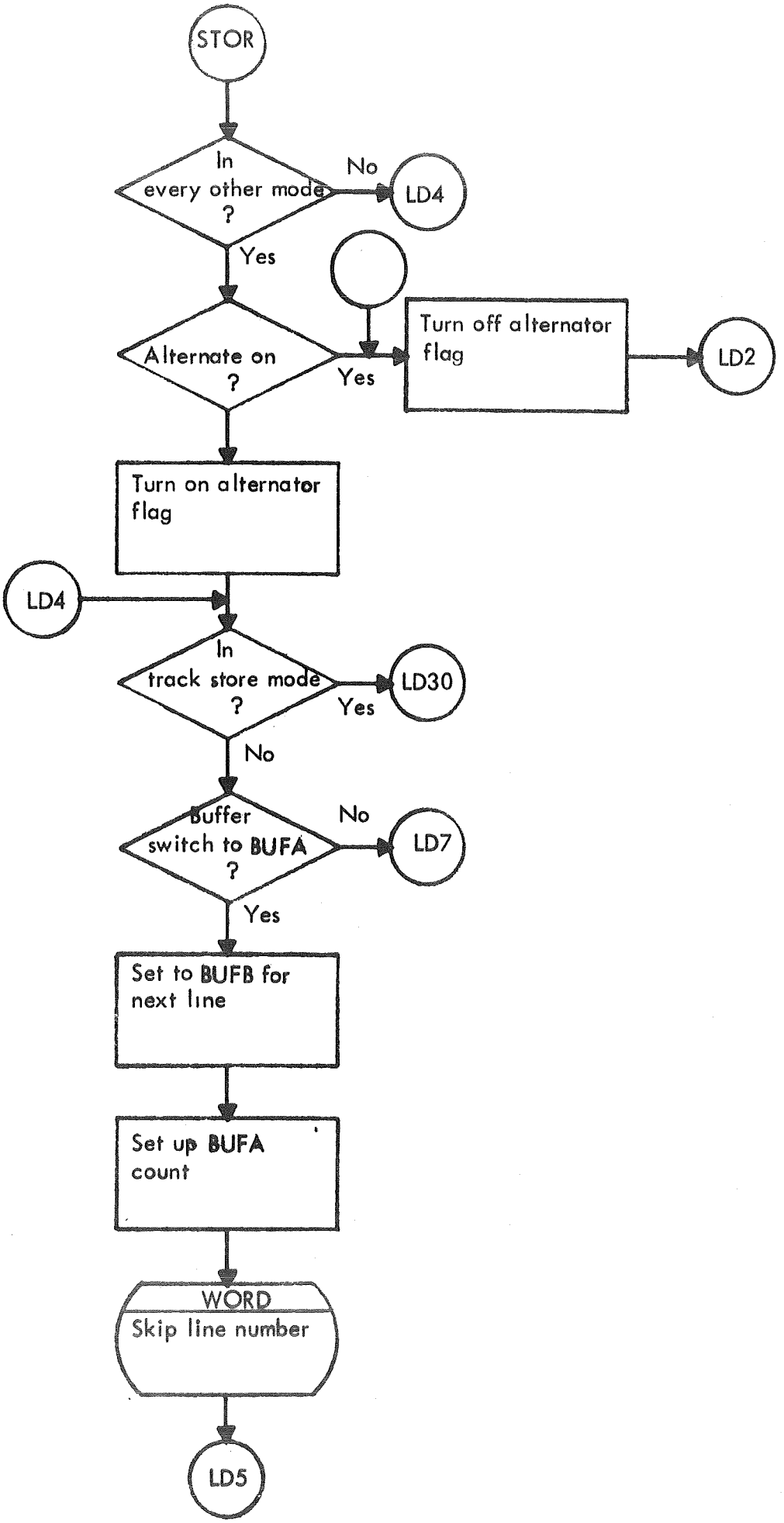


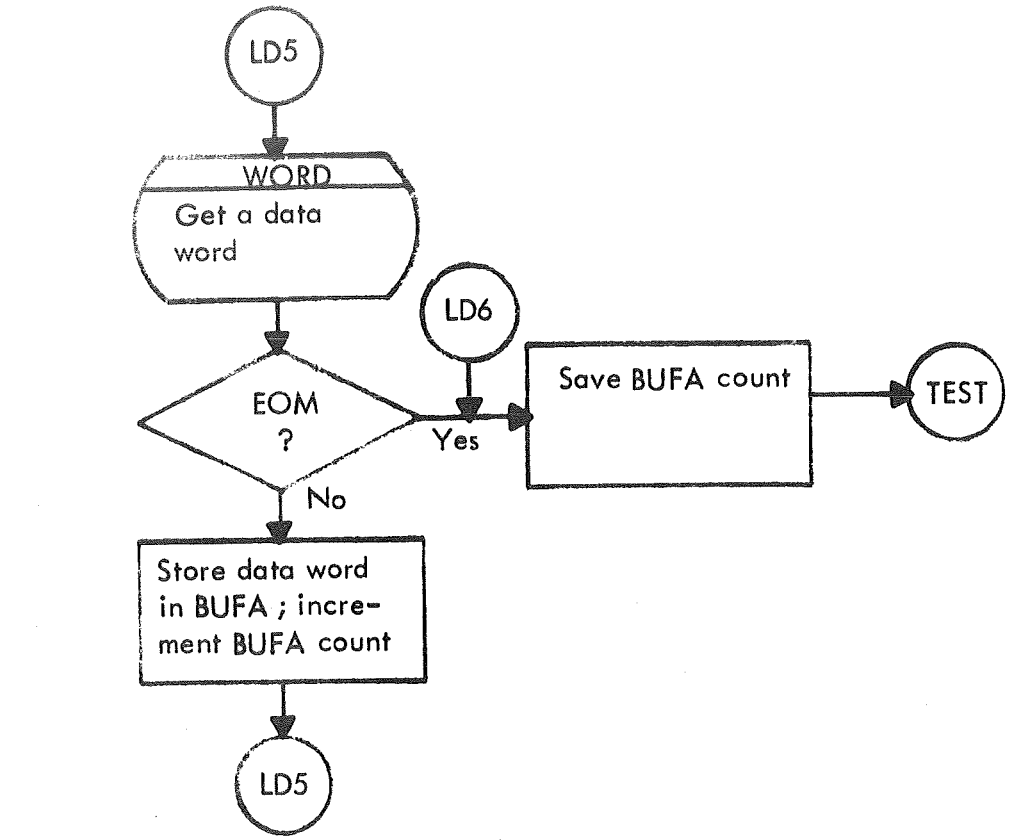
Switch the computer console to the A register, place the data tape in the reader, and press the START button. The tape will load and halt when the loading is completed, with control being transferred back to the display program.

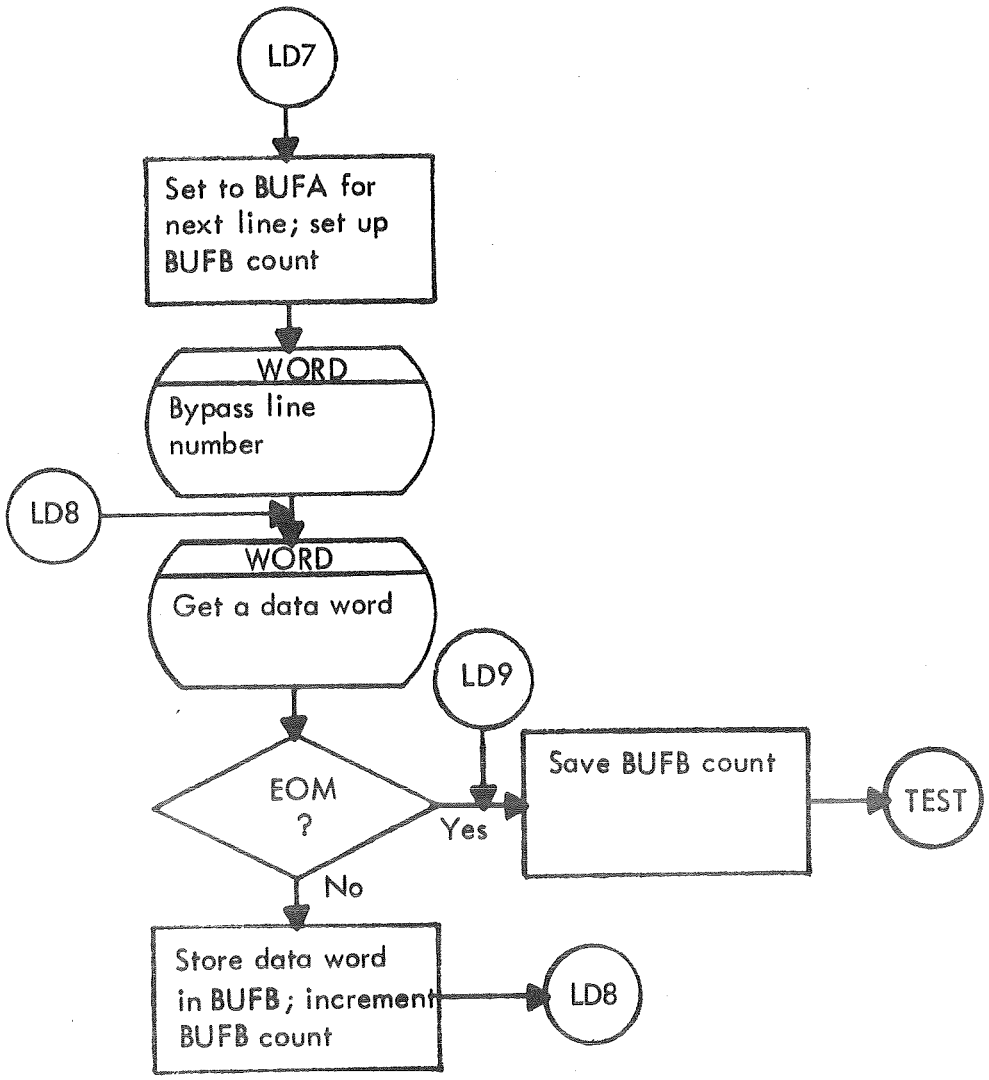
A flow diagram of the LOADER program follows this page.


LD1
TYPE
Type start and load A messages
Halt until A is loaded and start is hit
Store A-scan, re-fresh, every flag and starting line no
Start the reader; Reset load flag
LD2
STRC
Search until start code
Load flag on ?
Yes
STOR
No
WORD
Get line number
Line number match ?
No
LD2
Yes
4

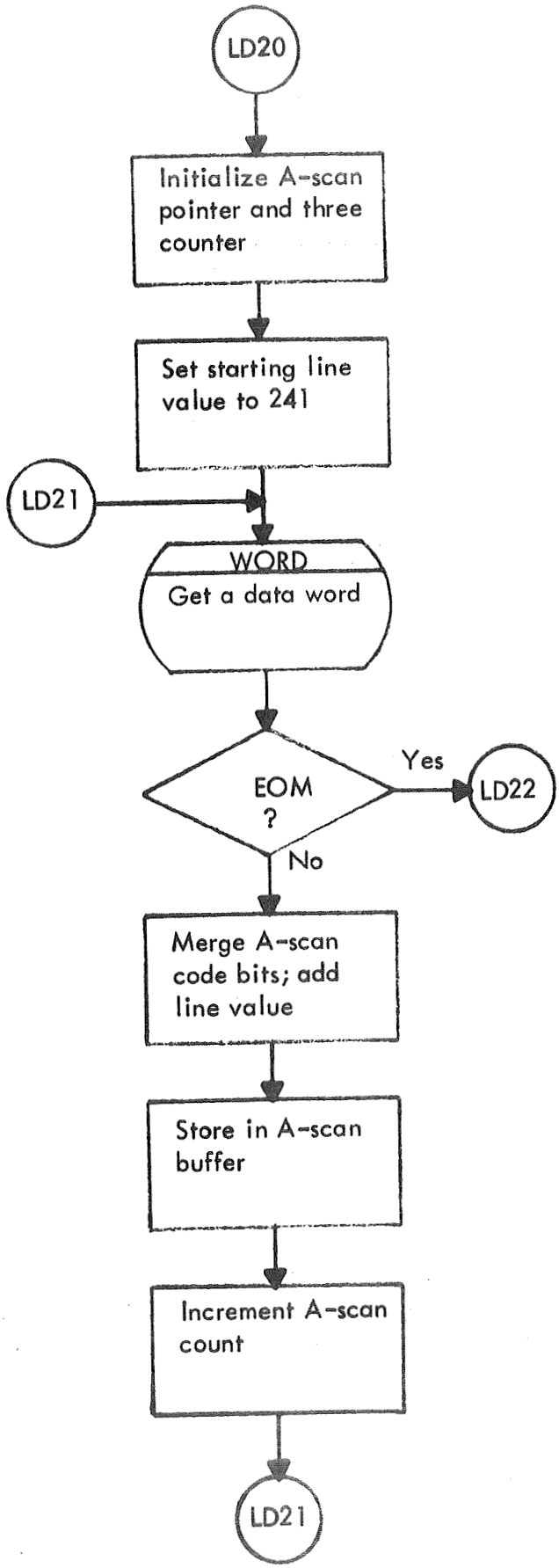

4
In A-scan mode ?
Yes
LD20
No
Set load flag
Initialize 240 line cntr every switch BUFA, BUFB, switch
LD3
Track store mode ?
Yes
Initialize track store counters
STOR
No
Initialize BUFA and BUFB
Initialize BUFA, BUFB counters
STOR

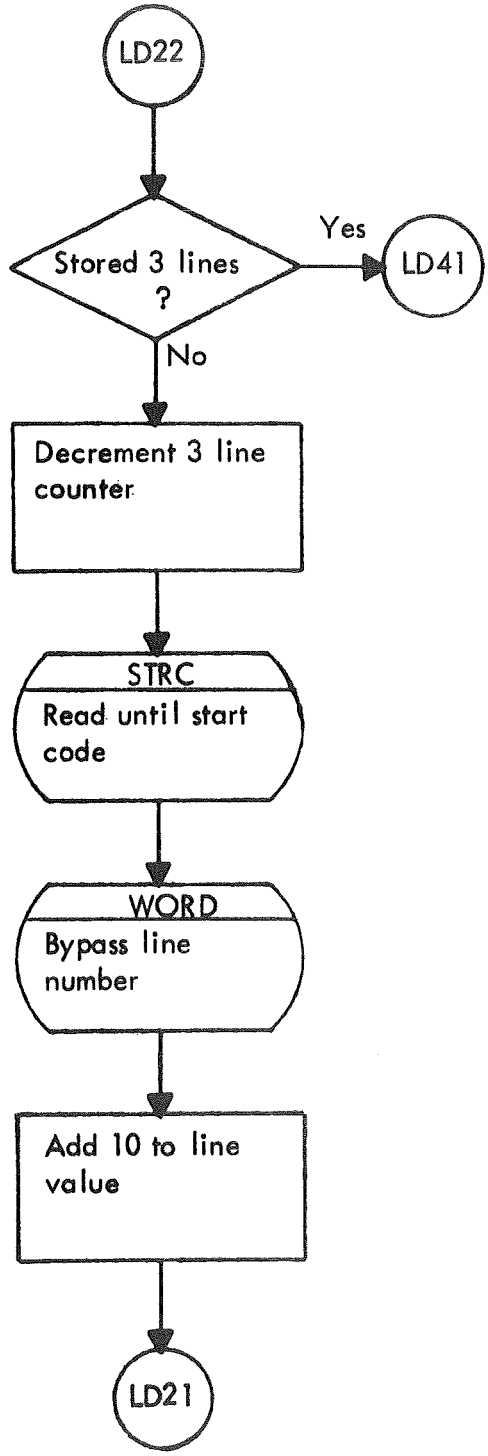

STOR
In every other mode ?
No
LD4
Yes
Alternate on ?
Yes
Turn off alternator flag
LD2
Turn on alternator flag
LD4
In track store mode ?
Yes
LD30
No
Buffer switch to BUFA ?
No
LD7
Yes
Set to BUFB for next line
Set up BUFA count
WORD
Skip line number
LD5


LD5
WORD
Get a data word
LD6
EOM ?
Yes
No
Save BUFA count
TEST
Store data word in BUFA ; increment BUFA count
LD5

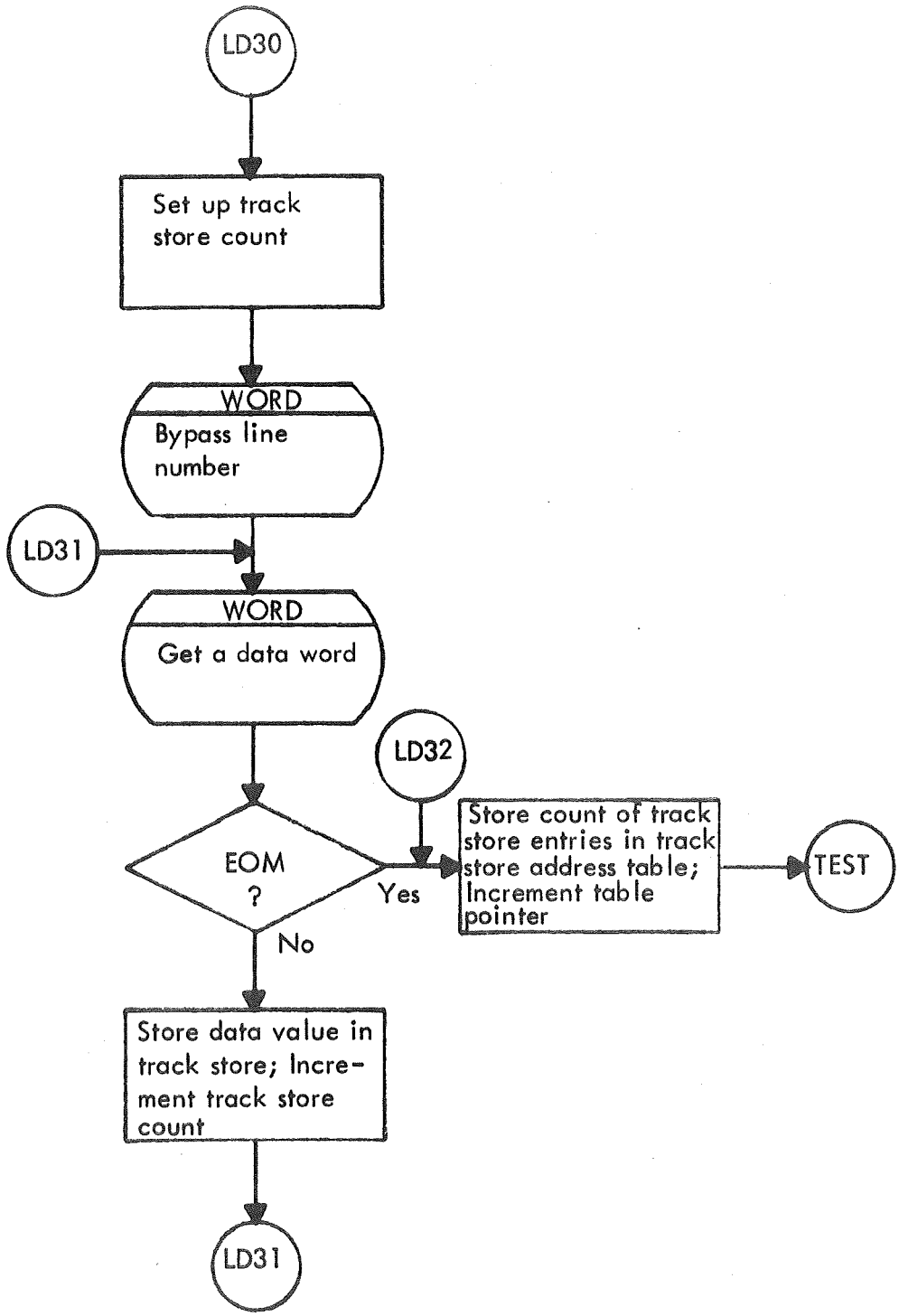

LD7
Set to BUFA for next line; set up BUFB count
WORD
Bypass line number
LD8
WORD
Get a data word
LD9
EOM ?
Yes
No
Save BUFB count
TEST
Store data word in BUFB; increment BUFB count
LD8

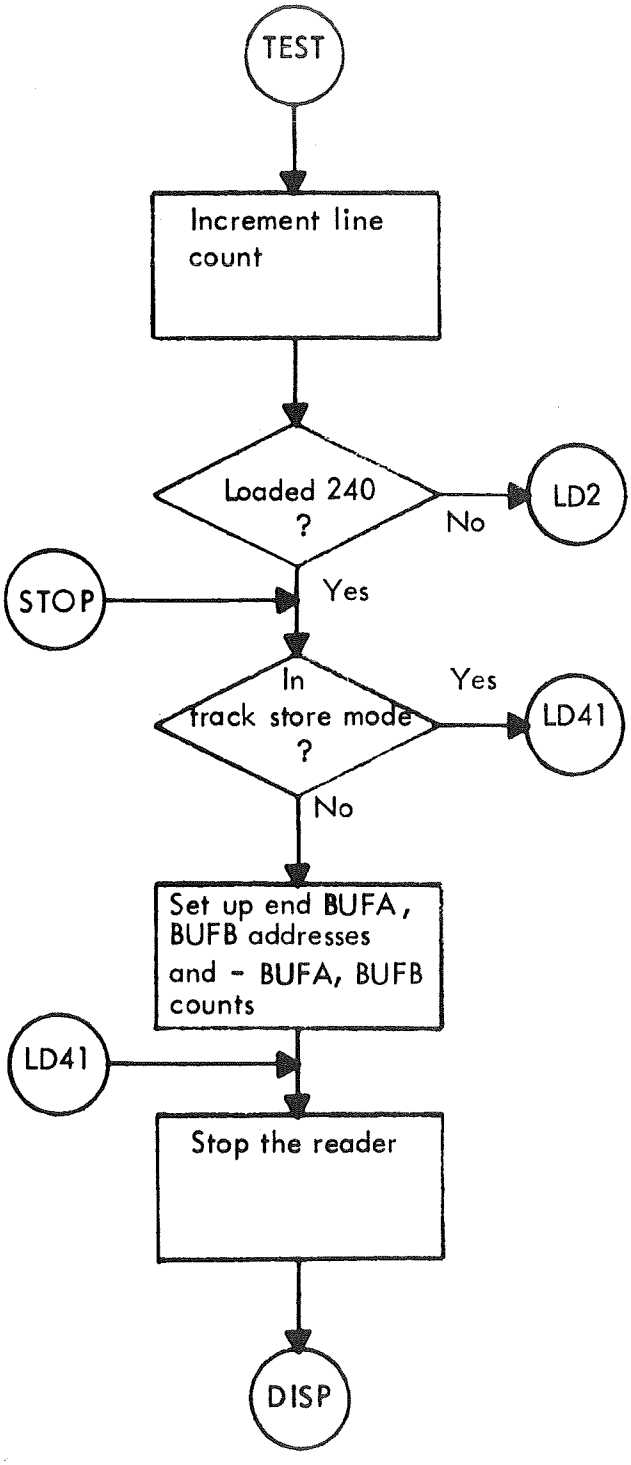
A-SCAN LOAD


LD20
Initialize A-scan pointer and three counter
Set starting line value to 241
LD21
WORD
Get a data word
EOM ?
Yes
LD22
No
Merge A-scan code bits; add line value
Store in A-scan buffer
Increment A-scan count
LD21


LD22
Stored 3 lines ?
Yes
LD41
No
Decrement 3 line counter
STRC
Read until start code
WORD
Bypass line number
Add 10 to line value
LD21

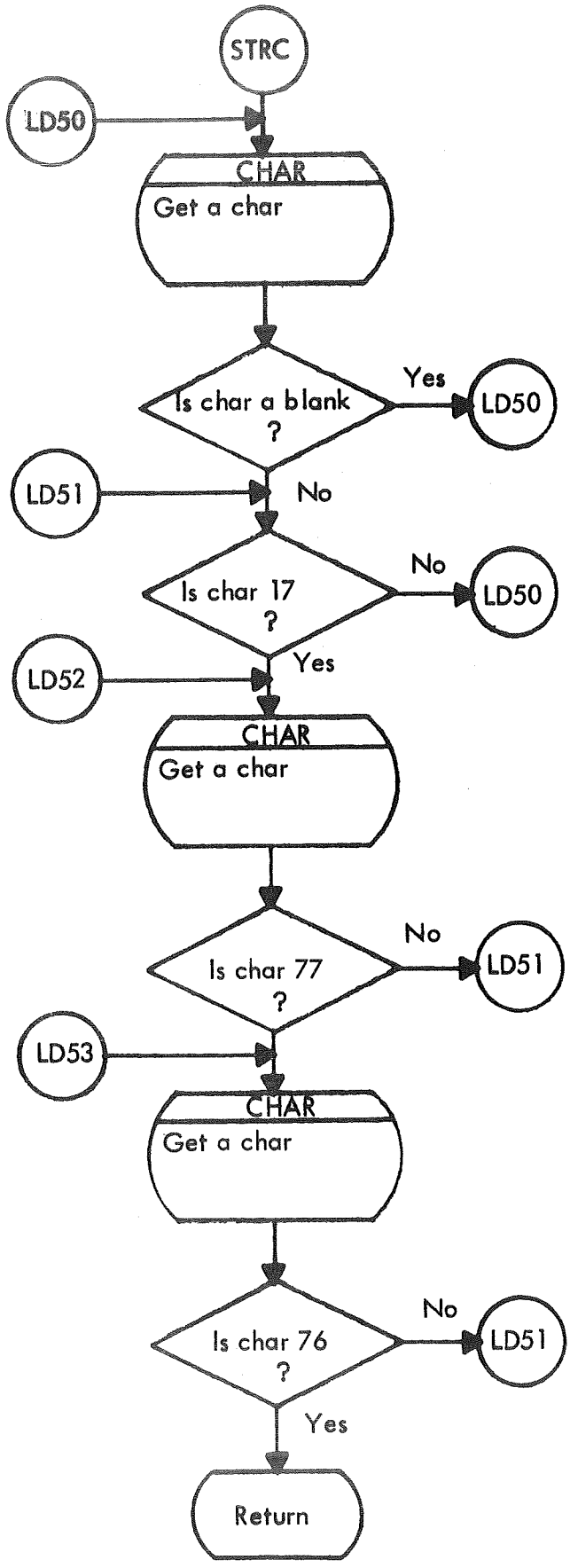
TRACK STORE


LD30
Set up track store count
WORD
Bypass line number
LD31
WORD
Get a data word
LD32
EOM ?
Yes
Store count of track store entries in track store address table; Increment table pointer
TEST
No
Store data value in track store; Increment track store count
LD31


TEST
Increment line count
Loaded 240 ?
No
LD2
Yes
STOP
In track store mode ?
Yes
LD41
No
Set up end BUFA, BUFB addresses and - BUFA, BUFB counts
LD41
Stop the reader
DISP

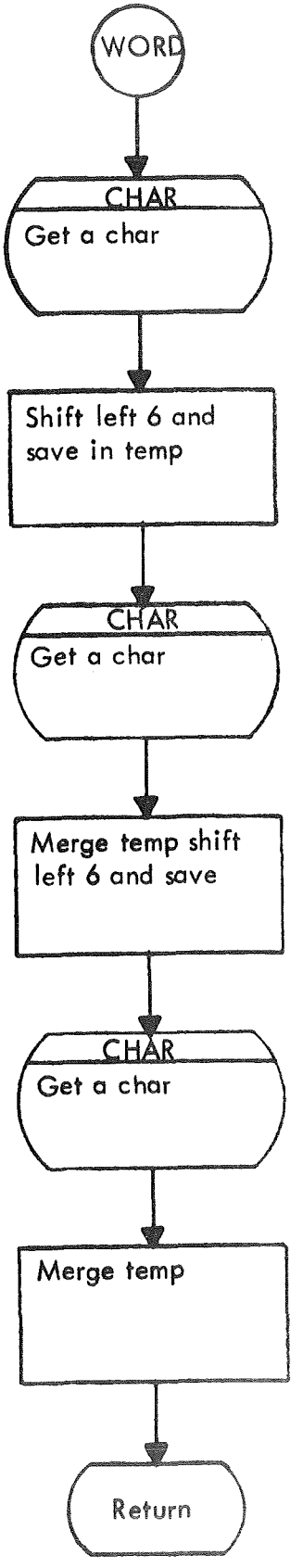
SUBROUTINE - Input - none

Output - read until start code



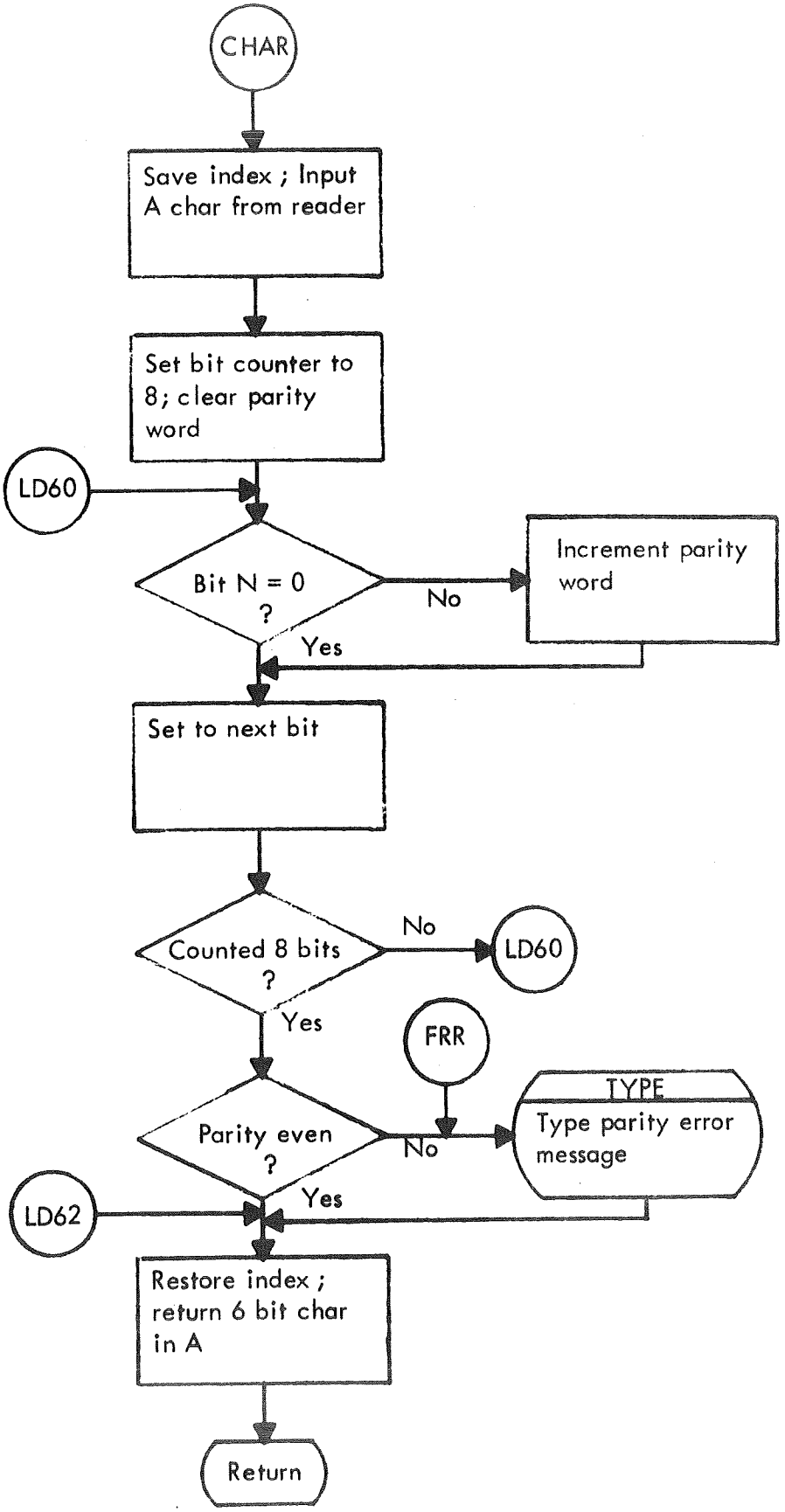
SUBROUTINE - Input - none

Output - three char word in A



SUBROUTINE - Input - none

Output - one char right justified in A

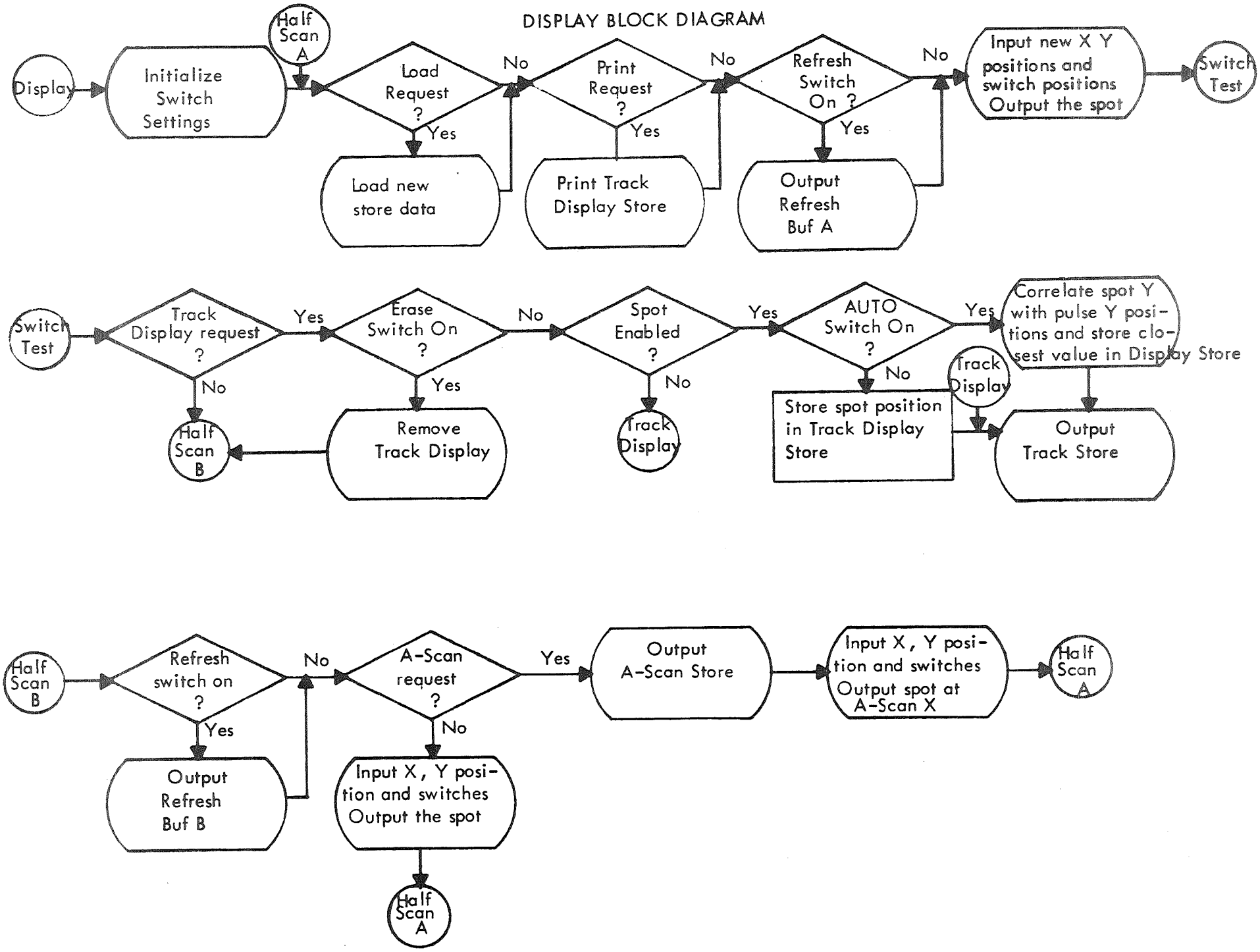


Display Program

The function of the Display program is to output data for the ionogram picture display on the CRT from the Refresh Store, as well as to display data from Track Store and A-scan Store. This program also provides the means by which the operator communicates with the computer in order to establish and update tracks and print out equivalent h'(f) data on the typewriter from Track Store. Each type of data produces a unique display and the movable cursor spot is like a pointer in the ionogram picture display which enables the operator to select data points for Track Store based on her interpretation of the X, O, or Z wave traces. Eight program control switches, located on a panel to the left of the cursor spot control mechanism, control the various display functions and permit loading and transfer of data from the operator to Track Store or correlation from pulse store and finally to typewriter printout which was the final data output device in the simulated system. Tracks can be established and updated in either auto-correlation or manual mode with the aid of the movable cursor spot. In auto-correlation mode, a search is made in Pulse Store to locate any pulse that might fall within the approximately 35 km window centered on the cursor spot. In manual mode, data from the cursor spot position is entered into Track Store when the ENABLE program control switch is closed.

i A flow diagram of the Display program follows this page.

DISPLAY BLOCK DIAGRAM



In this program the various buffers are linked in the Display program, depending on the settings of the program control switches. In one version of the Display program, data from Track Store was displayed for 10 consecutive frames and was off for four frames. This provided a means of causing the track display to blink to make the track display stand out from the ionogram trace on which it is superimposed. A test of this feature showed conclusively that it was not necessary to blink the track display in order to be able to recognize it clearly. The Display program was changed to delete this function. The display rate is dependent upon how many display buffers are linked into the Display program. No display is possible while buffers are being loaded or data from Track Store is being printed on the typewriter.

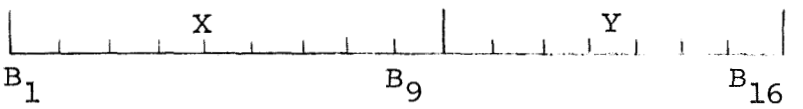
The display is blanked during the retrace portion of the raster, or when the Display program is changing over from one display mode to another.

Communication is maintained between the Display program and the display hardware by means of machine language instructions.

> OTA 0110 is the normal output command for X-words, Y incremental and direct skip words, G-words, and A-scan X-words.

OTA 0111 is a special G-word output command which instructs the hardware to hold one G character until another G-word is output.

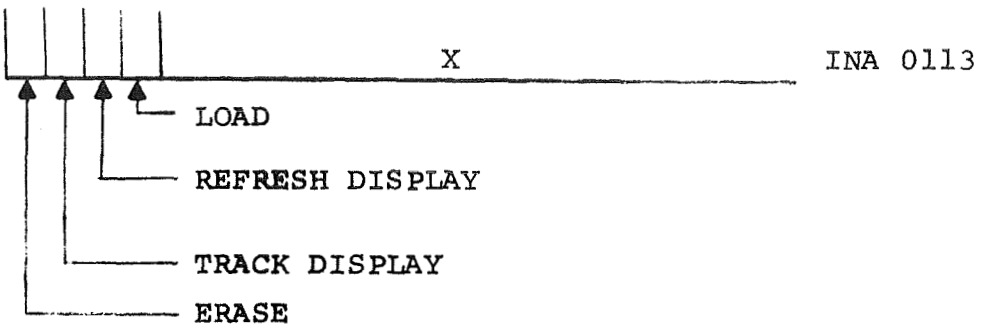
OTA 0112 is a special track display command which instructs the hardware to accept succeeding words as X, Y positions until another command is output. This instruction is used to transfer data from the Track Store to create the track display on the CRT.

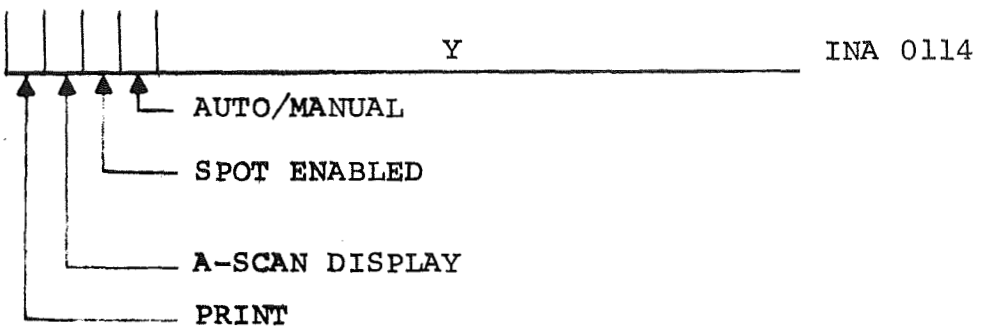


OTA 0112

INA 0113 is the command which is used to transfer data from track store through the interface hardware to track display on the CRT.

INA 0113 and INA 0114 are input commands for entry of X and Y coordinates representing the position of the cursor spot on the CRT display. With an INA 0113 input command, the first four bits of the word representing the X coordinate are flag bits which identify the positions of four of the program control switches. With an INA 0114 input command, the first four bits of the word representing the Y coordinate position of the cursor spot are flag bits which identify the positions of the remaining four program control switches. The computer word formats controlled by these input commands are shown on the following page.

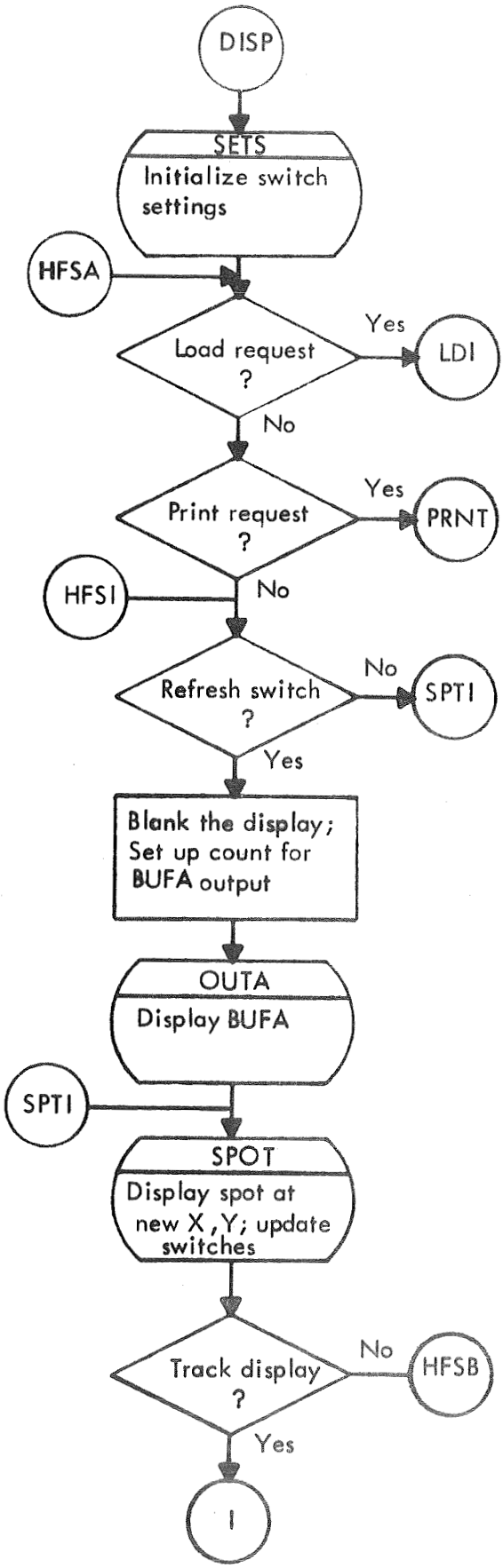


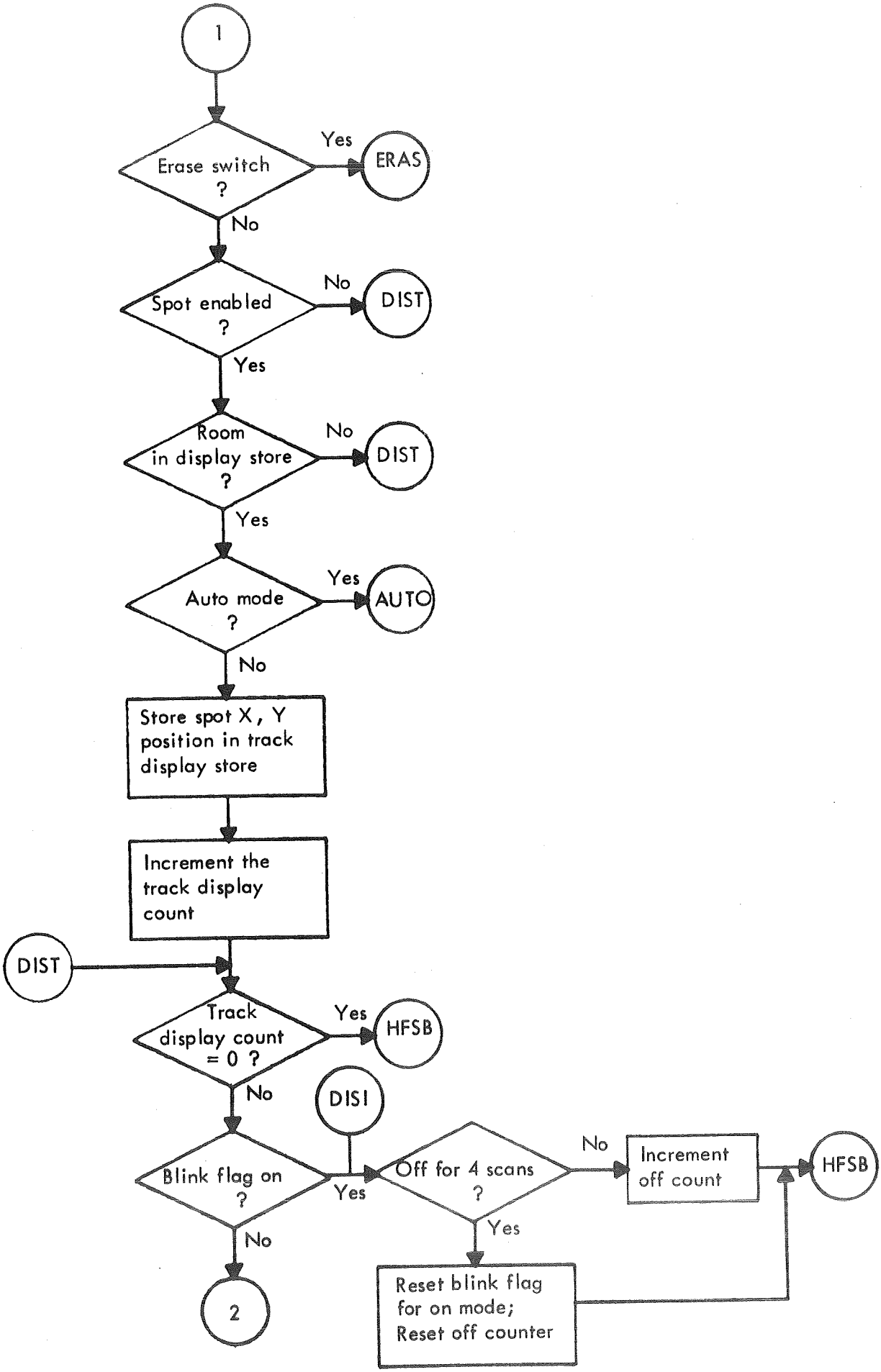


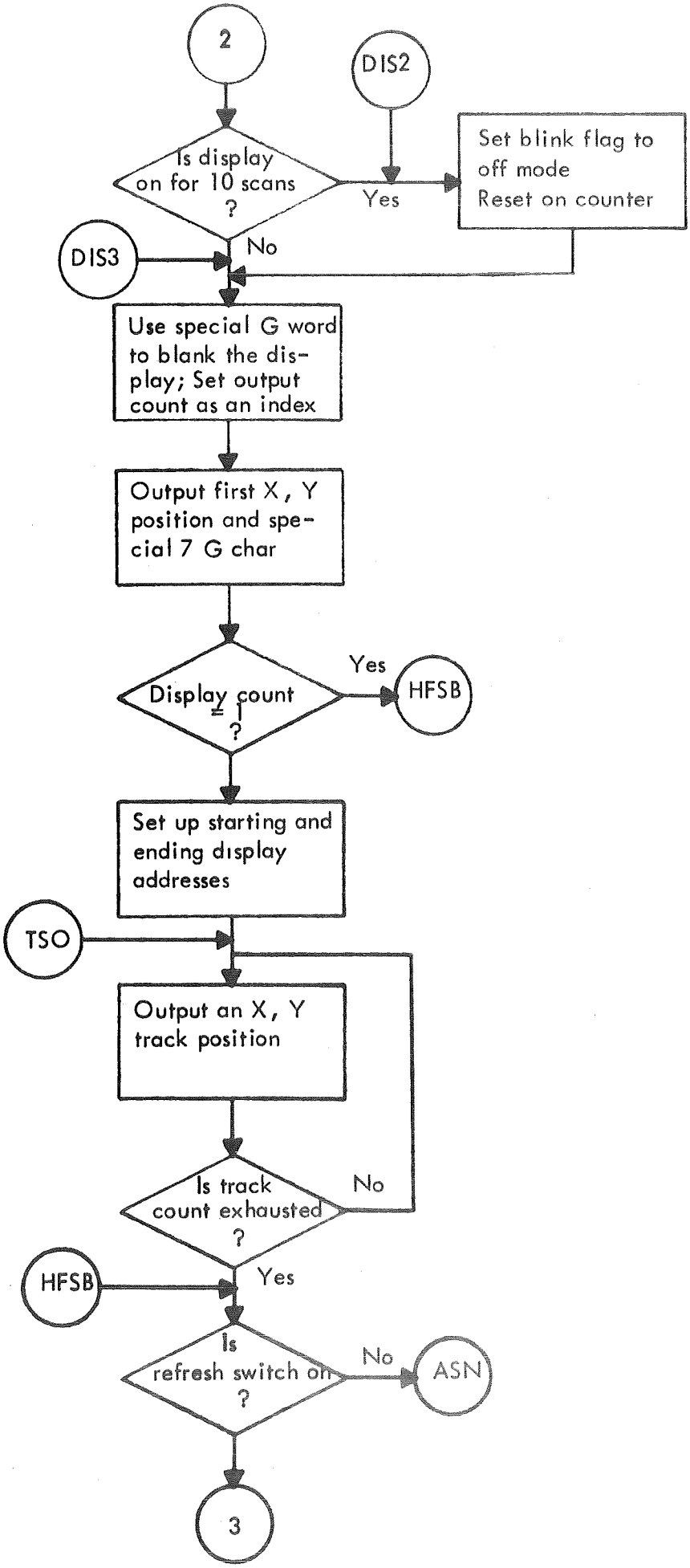
The Display Program can be loaded by either the high-speed paper tape reader or low-speed paper tape reader associated with the teletype unit. The display buffer information is loaded only on the high-speed reader.

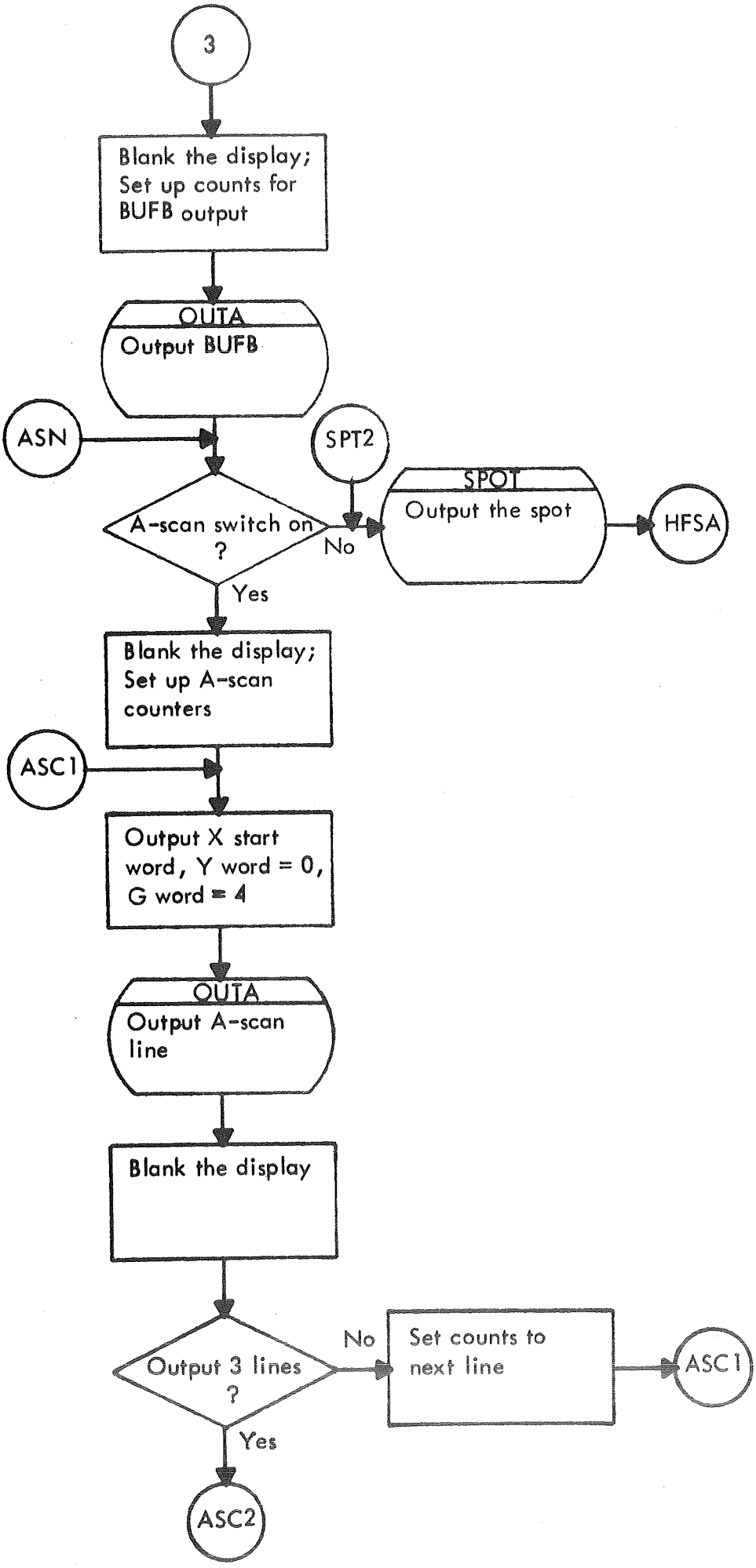
i A flow diagram of the Display Program follows this page.

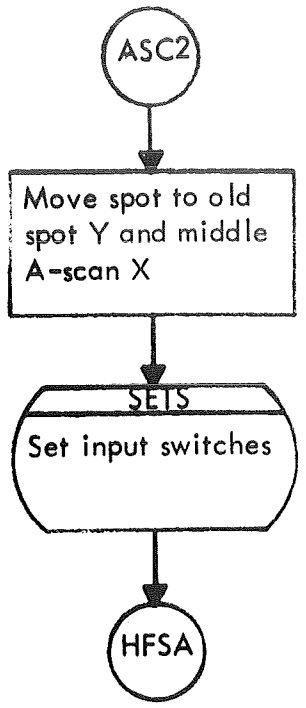
DISPLAY PROGRAM

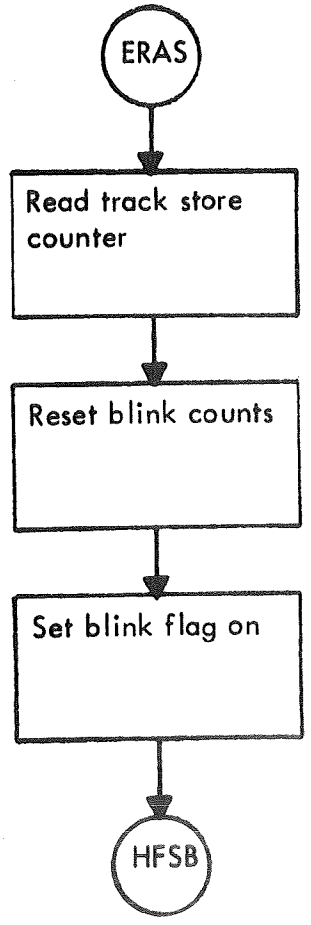


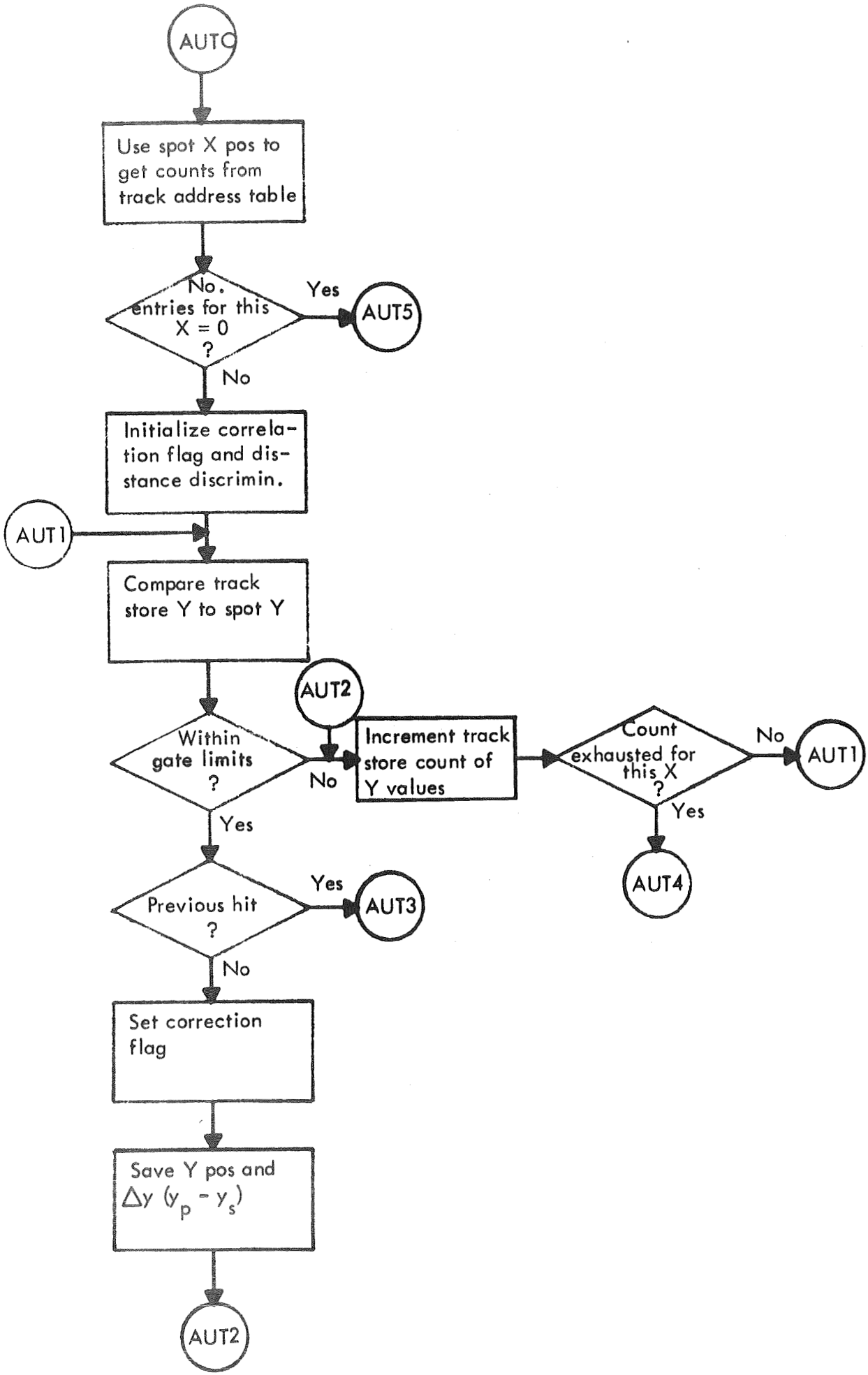

1
Erase switch ?
Yes
ERAS
No
Spot enabled ?
No
DIST
Yes
Room in display store ?
No
DIST
Yes
Auto mode ?
Yes
AUTO
No
Store spot X, Y position in track display store
Increment the track display count
DIST
Track display count = 0 ?
Yes
HFSB
No
DIS1
Blink flag on ?
Yes
Off for 4 scans ?
No
Increment off count
HFSB
Yes
No
2
Reset blink flag for on mode; Reset off counter

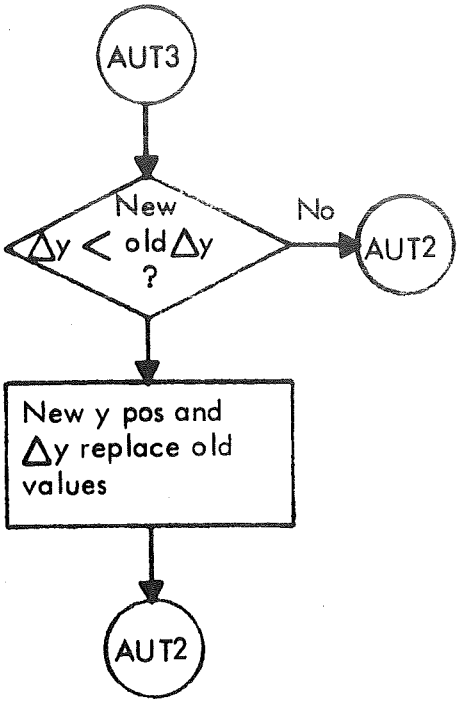

2
DIS2
Is display on for 10 scans ?
Yes
Set blink flag to off mode
Reset on counter
DIS3
No
Use special G word to blank the display; Set output count as an index
Output first X, Y position and special 7 G char
Display count = 1 ?
Yes
HFSB
Set up starting and ending display addresses
TSO
Output an X, Y track position
Is track count exhausted ?
No
HFSB
Yes
Is refresh switch on ?
No
ASN
3

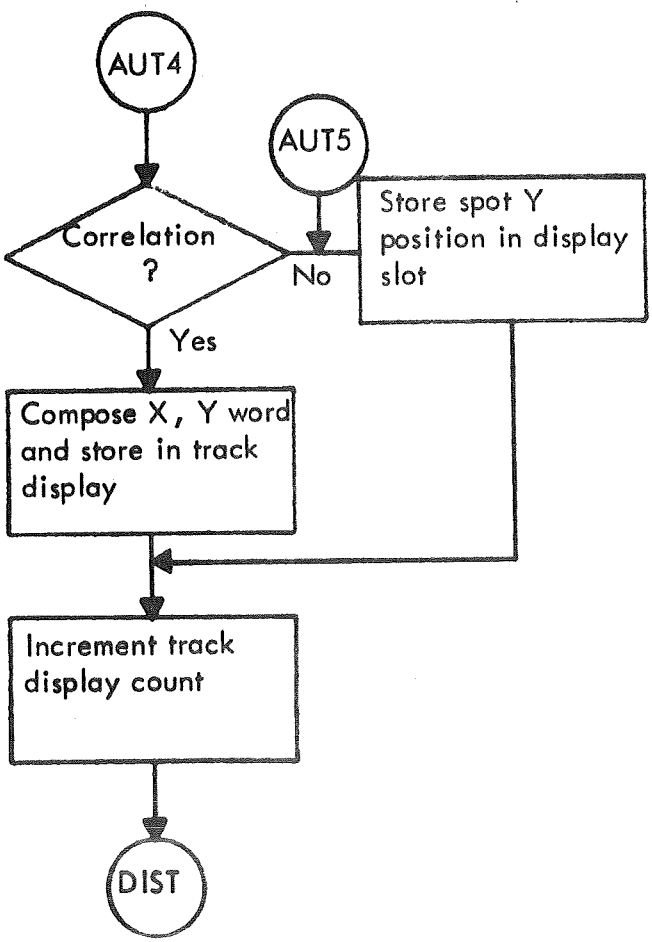

3
Blank the display; Set up counts for BUFB output
OUTA
Output BUFB
ASN
SPT2
A-scan switch on ?
No
SPOT
Output the spot
HFSA
Yes
Blank the display; Set up A-scan counters
ASC1
Output X start word, Y word = 0, G word = 4
OUTA
Output A-scan line
Blank the display
Output 3 lines ?
No
Set counts to next line
ASC1
Yes
ASC2

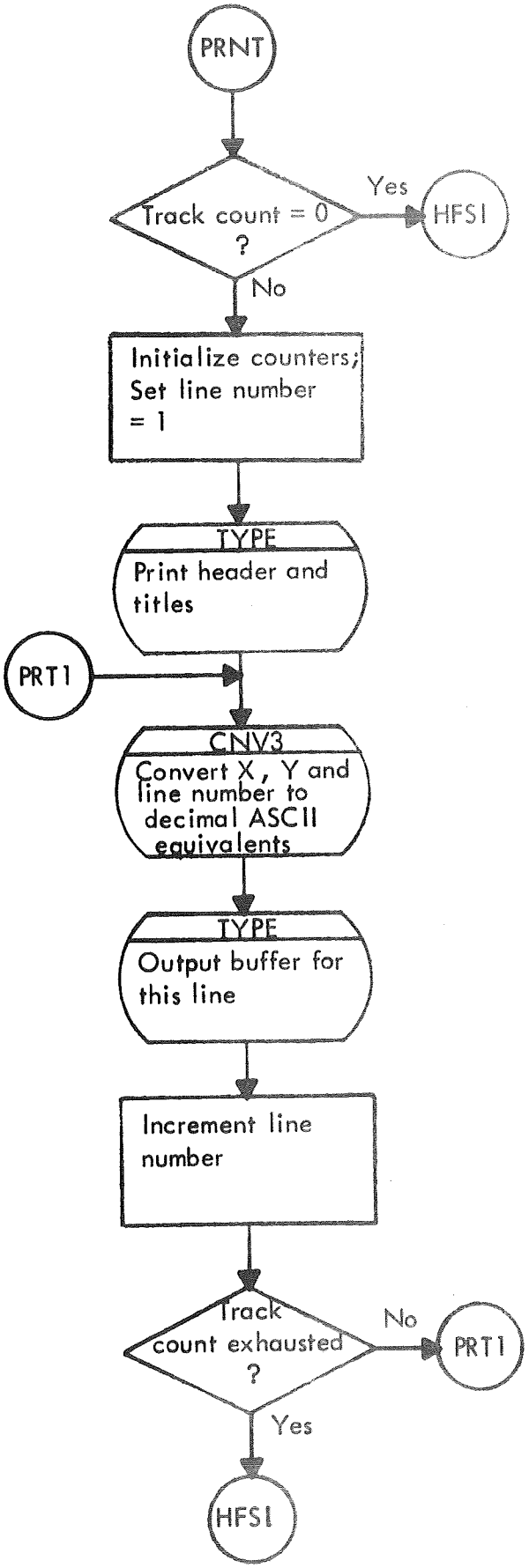

ASC2
Move spot to old spot Y and middle A-scan X
SETS
Set input switches
HFSA


ERAS
Read track store counter
Reset blink counts
Set blink flag on
HFSB


AUTO
Use spot X pos to get counts from track address table
No. entries for this X = 0 ?
Yes
AUT5
No
Initialize correlation flag and distance discrimin.
AUT1
Compare track store Y to spot Y
AUT2
Within gate limits ?
No
Increment track store count of Y values
Count exhausted for this X ?
No
AUT1
Yes
AUT4
Yes
Previous hit ?
Yes
AUT3
No
Set correction flag
Save Y pos and Δy (yp - ys)
AUT2


AUT3
New
Δy < old Δy
?
No
AUT2
New y pos and
Δy replace old
values
AUT2

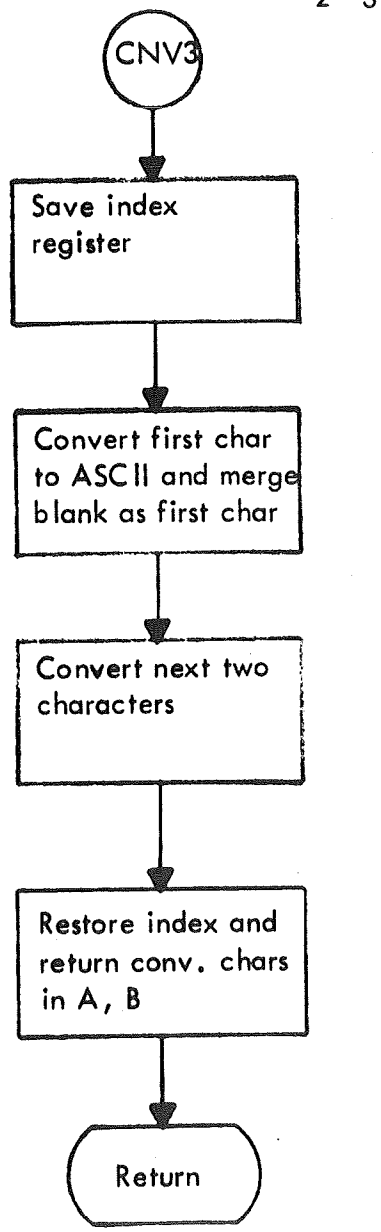

AUT4
AUT5
Correlation
?
No
Store spot Y
position in display
slot
Yes
Compose X, Y word
and store in track
display
Increment track
display count
DIST


PRNT
Track count = 0 ?
Yes
HFSI
No
Initialize counters; Set line number = 1
TYPE
Print header and titles
PRT1
CNV3
Convert X, Y and line number to decimal ASCII equivalents
TYPE
Output buffer for this line
Increment line number
Track count exhausted ?
No
PRT1
Yes
HFSI

SUBROUTINE - Input 9 lsb

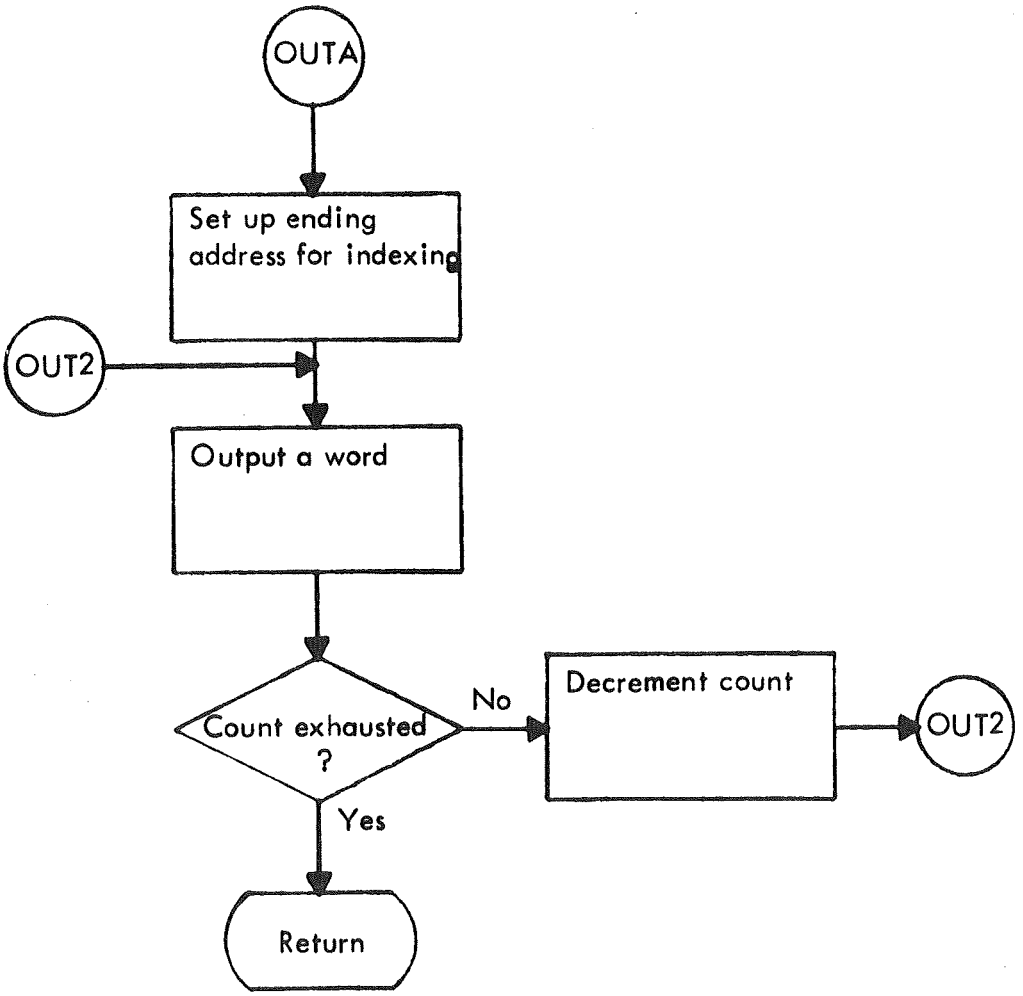
Output A = to C_1

B = C_2 C_3

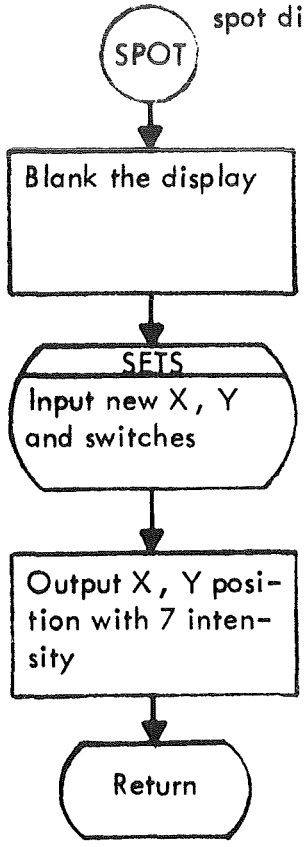

CNV3
Save index register
Convert first char to ASCII and merge blank as first char
Convert next two characters
Restore index and return conv. chars in A, B
Return

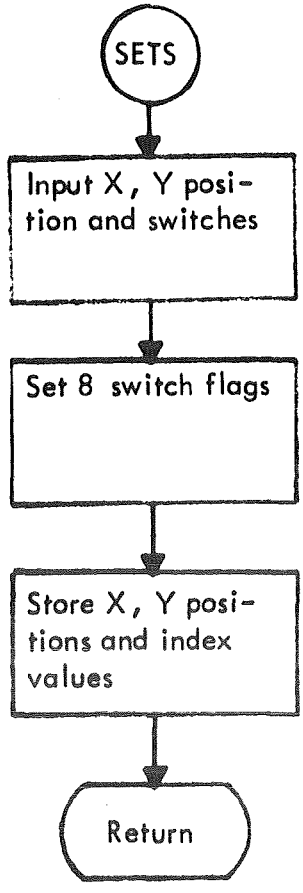
SUBROUTINE - Input - count in index
start add + count in A

Output - display



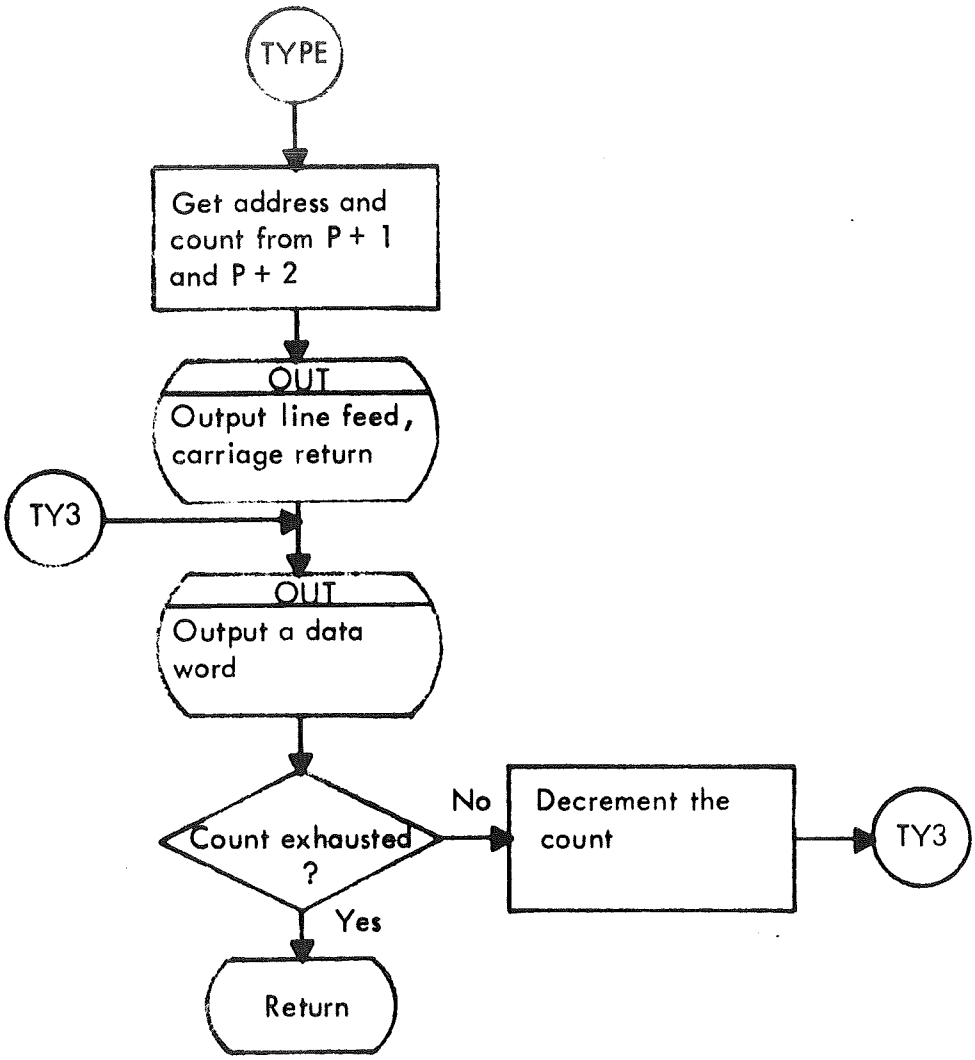
SUBROUTINE - Input - none
Output - stored position and switches
spot display





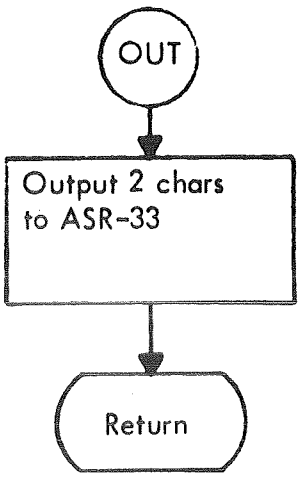
SUBROUTINE - Input - message address, count in words

Output - one line of printout



SUBROUTINE - Input - A = 2 chars to be output

Output - printed chars



GLOSSARY

ADC	Analog-to-digital converter.
CRT	Cathode ray tube.
CURSOR SPOT	A steerable bright dot used by an operator to designate a point within a computer-controlled display.
GRAY SCALE DATA	Four-valued information that determines the display CRT beam current for each element in the displayed image. (The beam current and spot dwell time together determine the intensity of each display element.)
h'(f)	A data point obtained from Topside Sounder data for use in computing the N(h) profile; virtual depth as F(Freq).
$\overline{h'(f)}$	A data point on an ionogram computed from the N(h) profile using the Inverse Program.
I/O	Input/Output.

PULSE STORE

In the proposed processor there will be no actual store that is labeled "Pulse Store". The term is retained, however to reference the record of echo pulse peaks that exist inherently in the A-Scan data file. Within the simulator the Pulse Store was a processor memory sector containing the h' values for all pulses detected along each video line. The locus of certain tracks could then be compared with the Pulse Store to obtain echo pulse range.

In the proposed processor the comparisons between tracks and detected pulses are confined to less than 30 lines specified by the data point selection rule being used. Further, the comparison will be limited to the h' region immediately surrounding the track.

REFRESH STORE

An independent area of core memory that contains the Gray Scale data to generate the real-time ionogram on the CRT display. The processor architecture is arranged so that memory access within this store (bank) does not steal cycles from the processor's main programs. This store is homogeneous in the sense that it may at times be employed in

normal fashion for other programs. When employed as conventional program or data store, this area of memory is indistinguishable from the remainder of core memory. Thus Refresh Store is available as additional time-shared core memory for contingencies.

TRACE — A set of echo pulses in an ionogram that form a discernible line or streak such as the regular X-wave or O-wave traces.

TRACE CORRELATION — A track is compared with detected pulses within the A-Scan information. Usually the comparison is confined to a prescribed region (window) near the track position, for example "within ±100 kilometers of the candidate track". The echo pulses within the window and closest to the candidate track are selected. The locus of echo pulse peaks selected in this manner is termed a correlated echo track.

TRACK — A set of data points introduced onto a display as the result of a conclusion. For example the operator may designate a track with the cursor that reflects her version, say of the X-trace. Similarly, the processor may create tracks that represent the results of correlation or inverse calculations, or an extrapolated estimate of a trace position.